1999

Optimal scheduling of Army initial entry training courses

Hall, Marie L.

Monterey, California; Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

OPTIMAL SCHEDULING OF ARMY INITIAL ENTRY TRAINING COURSES

by

Marie L. Hall

June 1999

Advisor:	David Olwell
Second Reader:	Michael McGinnis

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, Va 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE June, 1999	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE OPTIMAL SCHEDULING OF ARMY INITIAL ENTRY TRAINING COURSES			5. FUNDING NUMBERS
6. AUTHORS Hall, Marie L.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Training Development and Analysis Directorate HQ, TRADOC, Fort Monroe, VA			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE

13. ABSTRACT(*maximum 200 words*)

Scheduling Army enlisted initial entry training is a complicated task currently done manually at the U.S. Army Training and Doctrine Command Headquarters, Fort Monroe, Virginia. Scheduling results are entered into the Army's automated training system used by both training centers and recruiters to assign enlistees to training spaces at training centers. This thesis develops a mixed integer program to plan monthly training schedules for Basic Combat Training, One Station Unit Training, and Advanced Individual Training. The goals are to maximize the efficiency of the training schedule (by minimizing the number of recruits held over), to minimize the annual soldier training requirements not met, and to aspire to optimally fill courses. The model is implemented in the GAMS modeling language. The output is a matrix of 230 courses to 50 assigned start weeks. This approach accomplishes 94 percent of the annual Army requirements for fiscal year 2000 (FY00). Holdover time is decreased to 90,360 soldier-weeks using the optimal scheduling method compared with 180,000 weeks projected for FY00 using existing methods. This improvement saves 1800 soldier-years, or a brigade's worth of manpower for the Army at no additional cost. This approach effectively creates over 5500 additional training seats. This model should be implemented as a methodology for scheduling Initial Entry Training courses.

14. SUBJECT TERMS Optimization, Linear Programming, GAMS Integer Programming, Operations Research			15. NUMBER OF PAGES 89
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

OPTIMAL SCHEDULING OF ARMY INITIAL ENTRY TRAINING COURSES

Marie L. Hall
Captain, United States Army
B.S., United States Military Academy, 1992
M.E.M., Saint Martin's College, 1995

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 1999

ABSTRACT

Scheduling Army enlisted initial entry training is a complicated task currently done manually at the U.S. Army Training and Doctrine Command Headquarters, Fort Monroe, Virginia. Scheduling results are entered into the Army's automated training system used by both training centers and recruiters to assign enlistees to training spaces at training centers. This thesis develops a mixed integer program to plan monthly training schedules for Basic Combat Training, One Station Unit Training, and Advanced Individual Training. The goals are to maximize the efficiency of the training schedule (by minimizing the number of recruits held over), to minimize the annual soldier training requirements not met, and to aspire to optimally fill courses. The model is implemented in the GAMS modeling language. The output is a matrix of 230 courses to 50 assigned start weeks. This approach accomplishes 94 percent of the annual Army requirements for fiscal year 2000 (FY00). Holdover time is decreased to 90,360 soldier-weeks using the optimal scheduling method compared with 180,000 weeks projected for FY00 using existing methods. This improvement saves 1800 soldier-years, or a brigade's worth of manpower for the Army at no additional cost. This approach effectively creates over 5500 additional training seats. This model should be implemented as a methodology for scheduling Initial Entry Training courses.

EXECUTIVE SUMMARY

Scheduling Army basic training and advanced individual training classes week by week over a one year planning horizon is a complicated task currently done manually at the U.S. Army Training and Doctrine Command Headquarters, Fort Monroe, Virginia. Scheduling results are then entered into the Army's automated training system used by both training centers and recruiters to assign enlistees to training spaces at training centers. The current scheduling method results in bottlenecks at the reception battalions and mismatched seating capacity between Basic Combat Training (BCT) graduation and Advanced Individual Training (AIT) start weeks. This thesis develops an optimization model to find the optimal combination of course starts by week and by skill. The goals of the model are to minimize the annual soldier training requirements not met, minimize the number of recruits held over, and aspire to optimally fill courses. This model automates an extremely tedious and time-consuming manual process and produces much better schedules than are currently available.

Initial Entry Training (IET) scheduling poses unique challenges. Ten categories of recruits demand training seats at variable rates throughout the year. Recruits may be sent to any of five IET installations for in-processing followed by training. Four of the five installations offer both BCT and One Station Unit Training (OSUT). Soldiers who attend BCT at these five installations are then sent to one of 24 AIT schools to attend one of 185 AIT courses. For Fiscal Year 2000 (FY00), Army schedulers realize that there are not enough training resources to accomplish all of the Army training requirements. In fact, current projections indicate a shortage of over 50 BCT companies for the summer of FY00. This shortfall would result in 12,000 soldiers that the Army needs to fill projected losses, but lacks the resources to train, resulting in holdovers. Schedulers manually search for the combination of course starts, subject to system constraints, that will mitigate this potential resource crisis. Combinatorially this is an astronomical problem. The model developed in this

thesis to optimally schedule these courses consists of 44,000 variables and 116,789 single equations when applied to FY00 data. It is implemented with the General Algebraic Modeling System (GAMS).

This optimal scheduling model accomplishes some surprising results. By carefully combining the scheduled start of each course, 94 percent of the annual Army requirements for FY00 may be scheduled and actually accomplished. Soldier time in holdover status is decreased to 90,360 weeks using the optimal scheduling method compared with 180,000 weeks (which would result from the 50 BCT company shortfall). This is an improvement of 90,000 soldier-weeks, 1800 soldier-years, or a brigade's worth of manpower for the Army at no additional cost. This utilizes over 5500 training seats previously lost to inefficient schedules. The model levels course loads during non- summer months. This contributes to the quality of training that trainers may provide, and maximizes the flexibility of the schedule. This model also provides visibility of the IET system in its entirety in order to analyze the impact of policy decisions, resource levels and training quality, as well as to make optimal use of projected annual training resources. The model is easily adaptable to perform related analyses if there is interest in optimizing schedules with respect to alternate measures of performance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Active Component
AIT	Advanced Individual Training
AR	Army Regulation
ARPRINT	Army Program for Individual Training
ATRRS	Army Training Requirements and Resources System
BCT	Basic Combat Training
DEP	Delayed Entry Program
DP	Dynamic Program
FY	Fiscal Year
GAMS	General Algebraic Modeling System
IET	Initial Entry Training (OSUT or BCT plus AIT)
MEPS	Military Entry Processing Station
MIP	Mixed Integer Program
MOS	Military Occupational Specialty
NGB	National Guard Branch
NPS	Non-Prior Service
NCO	Non-Commissioned Officer
NT	No Training
ODCSPER	Office of the Deputy Chief of Staff for Personnel
ODCSOPS	Officer of the Deputy Chief of Staff for Operations
OPTEMPO	Operational Tempo
ORAD	Operations Research and Analysis Division of TDAD
OSUT	One Station Unit Training (Combined BCT and AIT)
POI	Program of Instruction

PS	Prior Service
ROTC	Reserve Officer Training Corps
SMDR	Structure and Manning Decision Review
TDAD	Training Development and Analysis Division of TRADOC
TOMA	Training Operations and Management Analysis Division of Training and Doctrine Command
TRADOC	Training and Doctrine Command
USAR	United States Army Reserve

ACKNOWLEDGMENTS

I wish to express my deep gratitude to my thesis advisor, LTC David Olwell for his exceptional patience, support, and advice. His enlightening critiques have made this thesis more understandable and precise.

I would like to express my sincere appreciation to LTC(P) Michael McGinnis for his insight and help as my second reader. I would like to especially thank him for allowing me to study his dissertation notes, background research, and literature reviews. This personal insight into his years of study and research into this very problem provided me with valuable insight and perspective.

Special thanks to Professor Gerald Brown for helping me with the mixed integer programming formulation, and implementation of the GAMS programming code.

I would like to express my appreciation to Mr. Seger, Assistant Deputy Chief of Staff for Training, U.S. Army Training and Doctrine Command (TRADOC), Fort Monroe VA, for sponsoring my experience tour and research. Thanks to COL Cheney for suggesting this thesis topic, endorsing my research, and providing her continued mentorship.

Special thanks to Mr. Robert Stevens, Chief, Operations Research and Analysis Division of the Training Development and Analysis Agency, for hosting my Experience Tour, providing me with valuable insight and understanding of the TRADOC organization and mission, and for acting as liaison throughout my study of this problem.

I would like to thank Mr. Tom Patrick and Mr. Ron Romero of the Training Operations Management Activity for sharing their insights into the complexities and realities of IET scheduling, and for all of the data used in this model.

My devotion and appreciation for the teamwork and support of my husband Andy, and our daughter Catherine. Thanks for your understanding, insightful critiques, love, and inspiration.

I. INTRODUCTION

A. ARMY INITIAL ENTRY TRAINING SYSTEM

The Army Office of the Deputy Chief of Staff for Personnel (ODCSPER) annually projects the number of expected losses of enlisted soldiers by special skill or Military Occupational Specialty (MOS) and pay grade for several years into the future. These projections are used to determine how many soldiers to recruit annually by MOS. The U.S. Army Training and Doctrine Command (TRADOC) must annually schedule enough Initial Entry Training (IET) courses to accommodate at least the projected number of recruits by MOS. Initial Entry Training consists of two sequential phases of training: Basic Combat Training (BCT) and Advanced Individual Training (AIT). For some MOSs, both phases are combined into one IET course called One Station Unit Training (OSUT). Each new soldier who joins the Army is contractually guaranteed an MOS. The recruit's choice of MOS is balanced against the needs of the Army.

After attending Basic Combat Training, each soldier who does not elect Split Option Training (defined below) attends AIT for MOS-specific training. The majority of Army recruits are recent high school graduates. Therefore, the demand for BCT seats is greater during the summer than other times of the year. Soldiers who have a contractual obligation to join the Army but are awaiting BCT are entered into the Delayed Entry Program (DEP). It is undesirable to postpone a recruit's BCT because of the increased probability that the recruitee will default on his or her contract and become a DEP loss. In addition to recent high school graduates, soldiers who have Split Option Training also compete for summer BCT seats.

Split Option training spreads the two phases (BCT and AIT) of IET over two summers, one normally prior to a soldier's high-school graduation. At some training locations, some BCT training areas (barracks, ranges, etc.) may be utilized by ROTC Camp thereby reducing the BCT capacity during the summer weeks that

these camps take place. Together, these factors of increased demand and reduced supply create what is known as *summer surge* for BCT units. There is more demand for BCT during summer surge than there is Army BCT capacity. The best use of BCT resources during the summer surge period is to make maximum use of all BCT companies.

BCT is only offered at five installations. It is designed to be the same for all soldiers. There are interdependencies, however, in that each BCT installation feeds AIT at particular installations. The Army Training Resource and Requirements Scheduling System (ATRRS) automatically pairs the geographically closest BCT and subsequent AIT for each recruit. By Army Regulation (AR) 350-10, *Management of Army Individual Training Requirements and Resources*, AIT school commanders have the authority to schedule their courses based on annual training requirements [Ref. 1]. Under current procedures, AITs are not allocated a portion of the BCT graduates. Instead, AIT schedulers generate a schedule that satisfies the annual training requirements and input that schedule into ATRRS. ATRRS provides some visibility of glaring discrepancies between the number of AIT seats compared with projected BCT graduates. Some schedules are altered and reprogrammed into ATRRS. Sometimes more classes are scheduled in ATRRS than are feasible. As a result of this manual give and take scheduling process, some summer BCT seats go vacant because there are not enough seats in follow-on AIT courses scheduled. At other times, AITs go partially filled because there are not enough BCT graduates. A soldier can only be scheduled for BCT if there is an AIT seat available for a course immediately following BCT graduation. These vacancies result in higher DEP loss and lower the likelihood of achieving fiscal year accession goals. In addition, when bottlenecks occur, the delay may prevent some recruits from arriving for scheduled classes.

B. CURRENT SCHEDULING METHOD

Two problems result from the current scheduling method. First, mismatched BCT and AIT enrollments result in inefficient use of training resources. Second, bottlenecks in the reception battalions result in inefficient use of trainee time. TRADOC needs a model that will balance projected BCT enrollments with subsequent AIT courses while simultaneously balancing competing demands for reception battalion resources. I will describe the current system to illustrate the need for a model that will schedule the number of course starts for each BCT, AIT and OSUT course by week across a one year planning horizon.

1. Basic Combat Training and OSUT Scheduling

During my experience tour at the TRADOC in Fort Monroe, Virginia, I worked in the Operations Research and Analysis Division (ORAD) of TDAD. I also worked closely with the Training Operations Management Activity (TOMA) which schedules all BCT, provides guidance to AIT centers, and assists with scheduling courses. During this experience tour, I discovered all BCT courses were scheduled by hand. Making changes to BCT course schedules was an arduous and tedious process. The human scheduler was an expert in this area and extremely dedicated and competent. While working in ORAD, we developed a spreadsheet model using the scheduler's scheduling rules and methodology that generates the required number of BCT starts per week. The model is used in conjunction with Microsoft Project to partial automate the scheduling process. This change alone adds enormous flexibility to the IET scheduling process. However, it fails to address allocation imbalances between BCT and AIT.

2. Advanced Individual Training Scheduling

In accordance with Army Regulation 350-10, AIT school commanders have the authority and responsibility for scheduling AIT [Ref. 1]. TOMA currently schedules all of the BCT courses. There is no system to ensure quantitatively that each

BCT seat has a follow-on AIT seat. In operations research terms, there are no balance equations to check whether or not the number of BCT graduates equals the number of available seats in the AIT courses that start the following week. All AIT commanders have an idea of the aggregate number of BCT graduates projected by week. However, they currently do not know, specifically, what their courses' fair share of those BCT graduates is relative to other AIT courses. This challenge motivated TOMA's request for the present study. A system that automates the scheduling process to distribute each AIT commander their fair share of BCT graduates would enable the AIT schedule to be managed so as to minimize disruption. A system that globally *optimizes* the use of all training resources would provide TOMA with enabling technology to provide timely qualitative scheduling guidance to subordinate commanders, without usurping those commanders' authority.

3. An Airline Metaphor

The IET schedule is a matrix of the number of course starts versus weeks of the fiscal year. The decision to schedule a course start in any given week is conditioned upon the availability of resources, the need of the Army to fill projected losses, and the anticipated number of soldier-students. The users of the training schedule also have competing demands. Recruiters and recruits desire a schedule that accommodates the expected recruit flow and provides a variety of course offerings. ODCSPER wants a schedule that accomplishes the mission assigned to TRADOC. The trainers, TRADOC, desire a schedule that maximizes quality of training and resources, by filling classes to their *optimal capacity.* Permanent party units desire a schedule that results in the timely arrival of skilled replacements who arrive at their unit with a positive attitude.

To describe this class of problem and illustrate the competing needs that the training schedule must meet, I will use an airline ticketing metaphor. In this metaphor, airline passengers represent new recruits, and travel agents are the recruiters. BCT followed by AIT can be viewed as two legs of a flight, while OSUT is

comparable to non-stop service. Completing an MOS-qualifying AIT or OSUT can be considered arriving at a destination. Training resources, such as training companies or class resources, in this metaphor are like the number of available aircraft. Once the training company has completed one cycle of a course (metaphorically, a flight), they become available to teach another cycle of a course (or available to be scheduled for another flight). Airlines will be most profitable if they provide flights where the passengers want to go when they want to go there. Passengers benefit from connecting flights that have short lay-overs. Profits will be maximized by flying airplanes with the optimal load of passengers. Pilots will perform better when the flights are scheduled at regularly recurring intervals and when they have adequate time to rest between flights. Reception battalions are the passenger lounges and have only a finite capacity. Using this metaphor, one can see how the IET training schedule, much like an airline schedule, provides a finite number of choices both in terms of start dates and type of training that the recruiter is able to offer a potential trainee. Therefore a desirable training schedule, from the perspective of the recruiter and recruit (metaphorically the travel agent and the passenger) is one that serves the needs of the recruit.

Any airline, like the Army training system, is constrained by availability of resources. A change in one flight has a domino-like effect on subsequent flights. Airlines are then not able to provide last minute flights to specific destinations on demand. Training schedules are prepared a year in advance. Final revisions to the schedule may be made three months in advance and the schedule is locked in six weeks in advance. Moreover, there is interdependence among resources throughout an airline schedule. For most training courses, there are multiple cycles of one type of training going on at one time. Each training course is made up of many blocks of instruction. Flights often rely on support beyond the flight crew, such as gate service and mechanics. Many training blocks require external support (outside the training company assets), such as ranges, training locations, hands-on training aids,

medic support, food service, and so on. These types of resources are shared among the other companies in training. Obviously the coordination can not be accomplished without an established training schedule.

One might think that if more recruits arrive than are expected for training in a given week that one can simply start one more class. Or if fewer arrive, that one could just push the scheduled start for a company back a week. From a practical standpoint this is virtually impossible. A shift of one week for a company would require re-coordinating all training resources; in the case of BCT, all coordinations for the following 11 weeks. If all companies were constantly trying to shift resources back and forth, the quality of training management would drop dramatically as requests went unfilled. As with an airline schedule, each scheduled cycle either goes on partially filled or is cancelled. In the case of over-fill, the excess recruits (passengers) must simply wait for the next available training seat. If the lounge is too full, they will crowd out passengers arriving for subsequent flights. Airline passengers who normally begin a two segment flight complete both segments. There must be enough flights scheduled to accommodate the number of reservations. Airlines over-book, in an attempt to generate full flights assuming some passengers will not show up.

This metaphor provides insight into the structure and complexity of the problem. However, the metaphor suggests that the measure of success for an airline is economic. IET scheduling is not profit driven. The combination of highly trained soldiers with the skills that are needed at the time that they are needed is a key component, if not the essential component, to maintaining a world-class Army. It follows then that the objective of optimizing the IET schedule is not specifically to save money. The objective is instead to provide the Army with its most critical resource, soldiers (not dollars), in the absolutely most effective way, subject to given resource constraints. This is a careful distinction from a modeling point of view, and motivates the development of the problem.

4. The Role of the IET Schedule

The ODCSPER and Office of the Deputy Chief of Staff for Operations (ODCSOPS) annually cohost the Structure Manning Decision and Review (SMDR). The purpose of the SMDR is to validate training requirements, and compare training requirements with training resources to form recommended training programs [Ref. 2]. The SMDR focuses on a fiscal year 28 months prior to execution. The SMDR takes approximately three weeks annually to conduct, and involves representatives from all organizations within the Army involved with staffing, funding, resourcing, recruiting, or providing training. The SMDR results in carefully selected, valid, and approved annual training requirements for each course. Scheduling IET courses in line with these annual requirements satisfies the needs of the Army and ultimately produces trained personnel. The primary measure of effectiveness of an IET schedule is how well it accomplishes the goals of the Army.

Once the annual training requirements have been established they are entered into ATRRS.

> The Army Training Requirements and Resources System (ATRRS) is the Department of the Army Management Information System of record for managing student input to training. The on-line system integrates manpower requirements for individual training with the process by which the training base is resourced and training programs are executed. This automation support tool establishes training requirements, determines training programs, manages class schedules, allocates class quotas, makes seat reservations, and records student attendance. It supports numerous Department of the Army processes to include the Structure Manning Decision Review (SMDR). The product of the SMDR is the Army Program for Individual Training (ARPRINT), the mission and resourcing document for the training base. [Ref. 3]

The ODCSPER projects recruit demand using the annual requirements as well as historical data. The ability of a schedule to provide training capacity that is in line with the projected recruit demand is the second most important measure of effectiveness for the training schedule.

Training seats must be available to meet demand. Recruiters have the difficult responsibility of enticing bright young high school graduates to join the Army. Demand peaks during the summer months. Recruiters take potential candidates with serious intent to join the Army to a local Military Entrance Processing Station (MEPS). It is here that a candidate is offered MOS choices for training that will be contractually guaranteed to that soldier. These opportunities are derived from comparing the soldier's abilities with the required skill set for that job. The ability to offer specific training to a potential recruit is subject to course schedules. Effective course scheduling can make the difference between bringing a desirable prospect into the Army and not.

Historically, there are occasions when soldiers sign a contract to enter the Army on a certain day but fail to show up at the BCT installation as required. The Army has implemented an automated system, called the *Request* system where recruiters reserve training seats for recruits. Training schedules from ATRRS are ported to the *Request* database. Through *Request*, recruiters may over-book scheduled training courses based on the anticipated no-show and attrition rates. Implemented effectively, these systems together provide the ability for trainers to manage their training plans and allow recruiters to achieve their mission.

A good IET training schedule must satisfy the competing demands of the recruits, the recruiters, and the trainers, while training a sufficient number of soldiers to provide replacements for anticipated Army losses. The training schedule must enable recruiters to provide a variety of choices to potential recruits, vary seat capacity which coincides with variable demand, and accommodate resource training constraints. The training schedule must strive to begin each class at its optimal capacity in order to produce high quality effective training. A schedule with these attributes would most efficiently train the force and fill critical shortages.

5. Modeling Approach

This thesis develops a mixed integer programming optimization model as a scheduling aid for TOMA. The model is implemented using the *General Algebraic Modeling System* (GAMS) and solved using the CPLEX solver on a WINTEL Pentium III desktop computer with 190 MB of RAM [Ref. 4].

The model optimally schedules BCT, AIT, and OSUT. To implement this model, the TOMA may enter the course resources parameters from ATRRS, and ODCSPER recruit projections in the GAMS model. Data from the previous Fiscal Year (FY) training schedule maybe input into the model using a spreadsheet interface. The output, a matrix of the number of weekly course starts across a one year planning horizon, is saved in a text file format that is easily readable by the Microsoft EXCEL spreadsheet package. The results can be used to provide scheduling guidance to each IET school commander based on SMDR annual training requirements, ODCSPER accession projections, and the best judgement of the decision maker.

C. RELATED RESEARCH

Scheduling problems are common to both military and civilian applications. This chapter discusses and compares closely related problems as well as alternative solution methods for the type of problem presented here.

Ward [Ref. 5] compares the Steady State Markov Chain model, simulation, and linear programming used for manpower planning models. His discussion illustrates the importance of carefully defining feasible state transitions. He also points out how linear programming techniques may incorporate multiple criteria, but priorities must still be assigned to each criterion. He also outlines the principal results of this class of model. In particular, Ward highlights the strategic viewpoint that manpower models may provide for clarification of policies, effects of those policies, and size and impact of the manpower variables.

Minimization of required resources is a common cost saving technique. Burns

[Ref. 6] develops a heuristic which creates a lower bound for multiple shift scheduling. Burns uses the lower bound to construct all schedules using exactly that lower bound across a specified planning horizon. Sklar [Ref. 7] develops a heuristic to minimize the total number of crews required to complete sortie missions for a specified time horizon. Chilson [Ref. 8] develops a mixed integer program to minimize Reserve Officer Training Corp temporary duty.

Researchers often develop heuristic methodologies for handling large scale and complex scheduling problems. Ignizio [Ref. 9] develops a two phase heuristic for scheduling training exercises. McGinnis provides the most closely related research in this area. McGinnis [Ref. 10] builds on Ignizio's scheduling method to develop both a heuristic method and a Dynamic Programming (DP) methodology for BCT scheduling. McGinnis develops a DP formulation which decomposes the problem into smaller components in order to size the training force to maximize the quality of training and schedule the training. Unlike McGinnis' model, the model of this thesis is restricted by the current force structure. The paradigm motivating McGinnis' research was to reduce the training system to most efficiently accommodate projected demand when demand in the foreseeable planning horizon was declining. My work presupposes an inability to change the force structure, while making most efficient use of available resources in an era of increasing demand on the training system.

Samms [Ref. 11] presents a heuristic methodology for scheduling courses at a Naval training facility. Samms' objective is resource leveling for one course. Samms suggests that his algorithm could be implemented for additional resources by weighting the additional resources based on their importance. This cannot be applied to the IET training schedule because the course schedules are not independent of one another. Rank ordering MOS producing courses by importance is a non-trivial task due to the inter-dependence among them. BCT courses provide input to AIT courses. OSUT and BCT courses must share reception battalion resources. This thesis does not attempt to level the flow of students through the training system. In fact, it is

known that the flow will not be level because there is a greater demand for potential recruits to begin training during the summer than at other times of the year. The training schedule attempts to accommodate the projected demand while making the best use of the available resources.

Integer and linear programming (LP) approaches are a common method for solving scheduling problems. Holloran [Ref. 12] uses integer and LP techniques as well as network optimization to develop an airline station manpower planning model. Holloran's model handles the entire scope of the scheduling process from forecasting to execution. Swords [Ref. 13] develops a model for military sortie scheduling. Also using LP methods, Rumchev [Ref. 14] uses linear systems of equations for controlling manpower systems scheduling. Rumchev's work highlights the critical requirement for balance of inputs at all echelons implementing balance difference equations. Lanzenauer [Ref. 15] uses LP for a production scheduling model. Lanzenauer's decision variables are used for deciding how much and when to produce an order to meet market requirements to optimize some well defined objective function. Seccatore [Ref. 16] proposes a combination of LP techniques and a heuristic algorithm for minimizing training facility requirements. His technique assumes a constant flow of students. As previously discussed, that assumption would not hold in the cases of this schedule. However, he also points out that carefully scheduling the convening of each section yields a minimum requirement of resources for a given time period. He suggests assigning a cost to each schedule based on specific measures of effectiveness and selecting the schedule with the cost that most exploits the measures of effectiveness. He discusses the fact that while this can be expressed in simple terms, it was for all practical purposes unsolvable for his thesis. He goes on to apply a heuristic algorithm. Interestingly, Seccatore's work was published in 1973. At that time the computing power to solve such a problem was unavailable. It is no longer beyond the current computing power to formulate and solve such a LP.

II. MODEL

A. PROBLEM DEFINITION

The primary shortcomings of the current scheduling systems are the absence of balanced allocation of BCT graduates among follow-on AIT courses, and poor allocation of reception battalion capacity among potential BCT and OSUT enrollees. TRADOC needs a scheduling model which provides the optimal global allocation of all training command resources. The best allocation of those resources meets projected demand for training (inputs) while accomplishing Army annual training requirements (output).

1. Training System Specifics

This thesis mathematically describes the flow of recruited soldiers from the time that they arrive at one of five primary Army Reception Battalions until they are qualified for assignment to an active duty, National Guard, or reserve unit. There are ten categories of recruits in the training system. All recruit categories must in-process at one of the five initial training installations: Fort Knox, Fort Sill, Fort Benning, Fort Leonard Wood, and Fort Jackson. In-processing takes place in the installation's reception battalion. Each reception battalion has a finite capacity, the number of soldiers that can be in-processed within one week. Recruits may not continue with training until they have completed in-processing. This normally takes three to five days to accomplish. However, soldiers may be delayed at the reception battalion due to either in-processing capacity limitations, or because they are waiting for an available course to begin.

The most common category of recruit is non-prior service Active Component (AC) recruits. There are two kinds of non-prior service recruits. Subject to contractual agreement, AC recruits will either attend BCT (AC-BCT) or OSUT (AC-OSUT). Non-prior service recruits who attend BCT will be scheduled for a subsequent AIT course. The most common type of National Guard and Reserve recruits attend sim-

ilar training paths, either BCT followed by AIT (NGB-BCT, USAR-BCT) or just OSUT (NGB-OSUT, USAR-OSUT). The National Guard and Army Reserves have an alternative training option which allows recruits to divide their training over two summers. Recruits scheduled only for BCT under this option are called split-option trainees (NGB-SPLIT, USAR-SPLIT). The AC also recruits soldiers who have prior service in the Army. These recruits have already attended Basic Training during a previous enlistment. Prior service recruits are sent directly to AIT for special skill training (AC-PS). Moreover, the AC is able to recruit some soldiers who do not have prior Army service but have some special skill that permits them to be sent directly to a permanent unit once they have in-processed without completing any additional training (NPS-NT). Figure 1 illustrates all possible paths a recruit may take through the IET system.

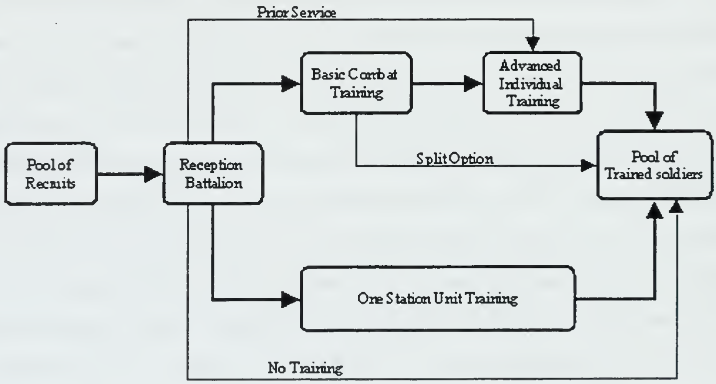

Figure 1. Network of Possible Recruit Paths

The manner in which a soldier can proceed with the training can be represented as a series of soldier-state transitions. The soldier enters *untrained* and proceeds through the IET system until he or she becomes available to replace personnel losses

in the respective Army component. The state describes a soldier's level of progress. As soldiers proceed through the system their state changes.

The ability of a particular recruit to transition from one state to another is dependent upon his or her category and the availability of training courses. Figure 2 illustrates all possible soldier-state transitions based on Figure 1.

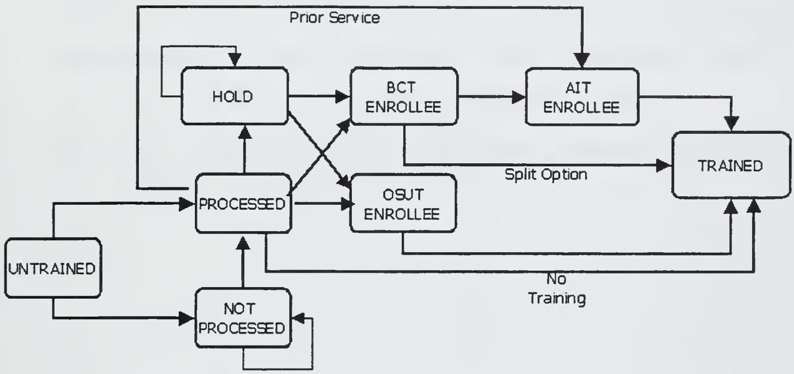

Figure 2. Soldier-State Transitions

Soldiers move through the system subject to an available sequence of course starts that will move the soldier from an untrained state to a trained state. Each course is resourced by either a training company or class. Resources are unique to the course they provide and are reusable. Each course is parameterized by its duration in weeks, and by its minimum, maximum, and predetermined optimal capacity in soldiers. The amount of time between soldier state-transitions and the number of soldiers in any state in a particular week may be computed subject to course scheduling decisions. Consequently, IET scheduling measures of performance such as recruit slack time, divergence from optimal course capacities, and percent of annual mission

requirements may be computed from the numerical values which describe each state. The objective of the IET system is to provide high quality training efficiently and effectively in order to provide trained soldiers to the force when needed with the skills that are needed.

2. Assumptions

- Course curricular, instructor, and training aid requirements are given in the Program of Instructions (POI). If the one company or section is provided to train a specific course, then that entity will be resourced to conduct such training.

- The existence of an available training unit (class or company) implies that the entity has all resources to provide course curricular, instructor, and training requirements that are given in the POI.

- Multiple instances of one type of course may be started simultaneously. The conduct of courses not integral to the IET system (NCO and officer training, for example) do not impede on the ability to freely schedule IET courses.

- Split Option trainees are given priority in filling BCT courses.

- Prior service, fully trained, and split-option recruit categories have priority for in-processing through the reception battalions.

B. INDICES

i	=	Basic Training and OSUT installations (Knox, Jackson, Leonard Wood, Benning, Sill)
y	=	fiscal year planning horizon (FY 00)
m	=	month of the fiscal year (OCT, NOV,... ,SEP)
w, w'	=	training weeks (5Oct98, 12Oct98, ... , 25Sep00)
wc	=	subset of w including only weeks within the current FY being scheduled by this model (4Oct99, 25Sep00)
wh	=	subset of w including only weeks from the historical FY (5Oct98, 26Sep99)
W	=	total number of elements in set wc, (50)
$HLAST$	=	The last week in the historical FY (26Sep99)
mw	=	set of month and week combinations unique to the FY being scheduled by this model
c	=	category and military component of recruit (USAR-SPLIT, USAR-OSUT, USAR-BCT, NGB-SPLIT, NGB-OSUT, NGB-BCT, AC-PS, NPS-NT, AC-OSUT, AC-BCT)
$creg$	=	subset of recruit categories that proceed to BCT or OSUT (USAR-SPLIT, USAR-OSUT, USAR-BCT, NGB-SPLIT, NGB-OSUT, NGB-BCT, AC-OSUT, AC-BCT)
$csplit$	=	subset of recruit categories including only Split Option (USAR-SPLIT, NGB-SPLIT)
$codd$	=	subset of recruits that do not go directly to BCT or OSUT (AC-PS, NPS-NT)
o	=	OSUT course titles
n	=	AIT course titles

C. DATA

1. Given Data

$recruit_{wc,c}$ the total expected number of soldiers to enter all Army reception battalions in week wc in category c (soldiers)

$rcap_i$ maximum number of soldiers that the reception battalion at installation i can process during one week (soldiers)

$oavail_{i,o}$ number of OSUT companies that provide training in MOS skill o, at training installation i (companies)

$oopt_o$ preferred number of soldiers per OSUT course o, also referred to as OSUT company size (soldiers)

$omin_o$ minimum number of students in an OSUT company o (soldiers)

$omax_o$ maximum number of students in an OSUT company o (soldiers)

$olength_o$ length of OSUT course o (weeks)

$oseat_m$ number of seats required by ODCSPER in order to meet projected demand by month (soldiers)

$oreq_o$ annual number of soldiers required by the Department of the Army to begin training in OSUT course o (soldiers)

$aopt_n$ preferred number of soldiers per AIT course n, also referred to as AIT course size (soldiers)

$amin_n$ minimum number of soldiers per AIT course n (soldiers)

$amax_n$ maximum number of soldiers per AIT course n (soldiers)

$alength_n$ length of AIT course n (weeks)

$areq_n$ annual number of soldiers required by the Department of the Army to begin training in AIT course n (soldiers)

$bavail_i$ number of BCT companies at training installation i (companies)

$bopt_i$ preferred number of soldiers per BCT course at installation i, also referred to as BCT company size (soldiers)

$bmin_i$	minimum number of soldiers per BCT company at installation i (soldiers)
$bmax_i$	maximum number of soldiers per BCT company at installation i (soldiers)
$blength_i$	length of BCT at installation i (weeks)
$bseat_m$	number of seats required by ODCSPER in order to meet projected demand by month (soldiers)

2. Initial Conditions

$ostart_{wh,i,o}$	initial start conditions for OSUT Companies. Number of OSUT company starts for weeks wh of the previous FY, per installation i, for course o. (course starts),(companies)
$bstart_{wh,i}$	Initial start conditions for BCT companies. Number of BCT company starts for weeks wh of the previous FY, per installation i. (course starts),(companies)
$astart_{wh,n}$	Initial start conditions for AIT courses. Number of AIT course starts for weeks wh of the previous FY, for course n. (course starts),(classes)
$benroll_{wh}$	Initial start conditions for BCT enrollees for weeks wh of the previous FY. (soldiers)
$splith_{wh}$	The total number of recruits arriving to attend split option training for both the reserve and National Guard components during weeks wh of the historical FY. (soldiers)
$notproch_{HLAST,i}$	The number of soldiers who are being held in the reception battalions but have not been in-processed due to capacity limitations during the last week of the historical FY at installation i. (soldiers)
$holdh_{HLAST,i}$	The number of soldiers who have been in-processed but are in a holdover status during the last week of the historical FY at installation i. (soldiers)
$proch_{HLAST,i}$	The number of soldiers who arrived and in-processed during the last week of the the historical FY, at installation i. (soldiers)
$acps_{HLAST}$	The number of active component prior service recruits that arrived for training during the last week of the historical FY. (soldiers)

3. Derived Data

$aavail_n$ number of AIT teaching teams that train soldiers in MOS skill, n. Derivation uses TRADOC resource management methodology(reusable training resource),(class team)

$aavail_n \equiv roundup \frac{areq_n * alength_n}{aopt_n * W}$

D. VARIABLES

1. Integer Variables

$OSTART_{wc,i,o}$ number of OSUT course starts in week wc, at installation i, to train MOS o. (companies)

$BSTART_{wc,i}$ number of BCT course starts in week wc, at installation i. (companies)

$ASTART_{wc,n}$ number of AIT course starts to train in week wc, for MOS n. (courses)

2. Continuous Variables

$HOLD_{wc,i}$	slack variable to allow demand that exceeds reception capacity in week wc to be carried over to week $wc+1$ at installation i. (soldiers)
$PROC_{wc,i}$	variable to distinguish recruits who are fully in-processed, in week wc, at installation i. (soldiers)
$PROC2_{wc,i}$	variable to distinguish recruits in week wc, at installation i who are in-processed but will not attend BCT or OSUT(AC-PS, NPS-NT recruits become PROC2). (soldiers)
$NOTPROC_{wc,i}$	variable to distinguish recruits who have not in-processed, in week wc at installation i. (soldiers)
$UNMETAIT_n$	slack variable for annual training requirement. Number n of seats that are under achieved. (soldiers)
$OVERAIT_n$	Number of seats by which the annual training requirement is exceeded for AIT course n. (soldiers)
$UNMETOSUT_o$	Number of seats that the annual requirement is under achieved for OSUT course o. (soldiers)
$OVEROSUT_o$	Number by which the annual training requirement is exceeded for OSUT course o. (soldiers)
$OENROLL_{wc,i,o}$	Number of students enrolled per company during week wc at installation i for OSUT course o. (soldiers)
$OTOOFEW_{wc,i,o}$	Elastic variables to permit fewer soldiers than the optimal capacity in week wc at installation i for course o. (soldiers)
$OTOOMANY_{wc,i,o}$	Elastic variables to permit more soldiers than the optimal capacity in week wc at installation i for course o. (soldiers)
$OMONTHO_m$	Permit more OSUT seats than required by ODCSPER in month m. (soldiers)

$OMONTHU_m$	Permit fewer OSUT seats than required by ODCSPER in month m. (soldiers)
$BENROLL_{wc,i}$	Number of students enrolled per company during week wc at installation i for BCT. (soldiers)
$BTOOFEW_{wc,i}$	Elastic variables to permit fewer soldiers than the optimal capacity in week wc at installation i. (soldiers)
$BTOOMANY_{wc,i}$	Elastic variables to permit more soldiers than the optimal capacity in week wc at installation i. (soldiers)
$BMONTHO_m$	Permit more BCT seats than required by ODCSPER in month m. (soldiers)
$BMONTHU_m$	Permit fewer BCT seats than required by ODCSPER in month m. (soldiers)
$AENROLL_{wc,n}$	Number of students enrolled per company during week wc for AIT course n. (soldiers)
$ATOOFEW_{wc,n}$	Elastic variables to permit fewer soldiers than the optimal capacity in week wc in course n. (soldiers)
$ATOOMANY_{wc,n}$	Elastic variables to permit more soldiers than the optimal capacity in week wc in course n. (soldiers)

E. FORMULATION

1. Objective Function

$$
\begin{aligned}
min = &\sum_{o} 50 * UNMETOSUT_o + \sum_{o} 50 * OVEROSUT_o \\
&+ \sum_{n} 50 * UNMETAIT_n + \sum_{n} 50 * OVERAIT_n \\
&+ \sum_{m} 4 * BMONTHU_m + \sum_{m} 4 * BMONTHO_m \\
&+ \sum_{m} 4 * OMONTHU_m + \sum_{m} 4 * OMONTHO_m \\
&+ \sum_{wc}\sum_{i} HOLD_{wc,i} + \sum_{wc}\sum_{i} NOTPROC_{wc,i} \\
&+ \sum_{wc}\sum_{n} (1/50) * ATOOFEW_{wc,n} + \sum_{wc}\sum_{n} (1/50) * ATOOMANY_{wc,n} \\
&+ \sum_{wc}\sum_{i}\sum_{o} (1/200) * OTOOFEW_{wc,i,o} + \sum_{wc}\sum_{i}\sum_{o} (1/200) * OTOOMANY_{wc,i,o} \\
&+ \sum_{wc}\sum_{i} (1/200) * BTOOFEW_{wc,i} + \sum_{wc}\sum_{i} (1/200) * BTOOMANY_{wc,i}
\end{aligned}
\tag{2.1}
$$

2. Constraints

$$
\begin{aligned}
&\sum_{creg} recruit_{wc,creg} + \sum_{i} NOTPROC_{wc-1,i} + \sum_{i} notproch_{wc-1,i} \\
&\quad = \sum_{i} NOTPROC_{wc,i} + \sum_{i} PROC_{wc,i} \ \forall wc
\end{aligned}
\tag{2.2}
$$

$$\sum_{codd} recruit_{wc,codd} = \sum_{i} PROC2_{wc,i} \ \forall wc \tag{2.3}$$

$$PROC_{wc,i} + PROC2_{wc,i} \le rcap_i \ \forall wc, i \tag{2.4}$$

$$\sum_{csplit} recruit_{wc,csplit} \le \sum_{i} PROC_{wc,i} \ \forall wc \tag{2.5}$$

$$
\begin{aligned}
&holdh_{wc-1,i} + HOLD_{wc-1,i} + proch_{wc-1,i} + PROC_{wc-1,i} = \\
&HOLD_{wc,i} + BENROLL_{wc,i} + \sum_{o} OENROLL_{wc,i,o} \ \forall wc, i
\end{aligned}
\tag{2.6}
$$

$$
\begin{aligned}
&BENROLL_{wc,i} + BTOOFEW_{wc,i} = \\
&bopt_i * BSTART_{wc,i} + BTOOMANY_{wc,i} \ \forall wc, i
\end{aligned}
\tag{2.7}
$$

$$BTOOFEW_{wc,i} \leq (bopt_i - bmin_i) * BSTART_{wc,i} \ \forall wc, i \tag{2.8}$$

$$BTOOMANY_{wc,i} \leq (bmax_i - bopt_i) * BSTART_{wc,i} \ \forall wc, i \tag{2.9}$$

$$\sum_{wc \in m} \sum_i BENROLL_{wc,i} + BMONTHU_m = bseat_m + BMONTHO_m \ \forall m \tag{2.10}$$

$$\sum_i BENROLL_{wc,i} \geq \sum_{csplit} recruit_{wc-1,csplit} + splith_{wc-1} \ \forall wc \tag{2.11}$$

$$\begin{aligned} &OENROLL_{wc,i,o} + OTOOFEW_{wc,i,o} = \\ &oopt_o * OSTART_{wc,i,o} + OTOOMANY_{wc,i,o} \ \forall wc, i, o \end{aligned} \tag{2.12}$$

$$OTOOFEW_{wc,i,o} \leq (oopt_o - omin_o) * OSTART_{wc,i,o} \ \forall wc, i, o \tag{2.13}$$

$$OTOOMANY_{wc,i,o} \leq (omax_o - oopt_o) * OSTART_{wc,i,o} \ \forall wc, i, o \tag{2.14}$$

$$\sum_{wc \in m} \sum_i \sum_o OENROLL_{wc,i,o} + OMONTHU_m = oseat_m + OMONTHO_m \ \forall m \tag{2.15}$$

$$\begin{aligned} &AENROLL_{wc,n} + ATOOFEW_{wc,n} = \\ &aopt_n * ASTART_{wc,n} + ATOOMANY_{wc,n} \ \forall wc, n \end{aligned} \tag{2.16}$$

$$ATOOFEW_{wc,n} \leq (aopt_n - amin_n) * ASTART_{wc,n} \ \forall wc, n \tag{2.17}$$

$$ATOOMANY_{wc,n} \leq (amax_n - aopt_n) * ASTART_{wc,n} \ \forall wc, n \tag{2.18}$$

$$\begin{aligned} &benrollh_{wc-10} + \sum_i BENROLL_{wc-10,i} + acps_{wc-1} + recruit_{wc-1,\text{“}AC-PS\text{”}} \\ &= \sum_n AENROLL_{wc,n} + \sum_{csplit} recruit_{wc-11,csplit} + splith_{wc-11} \ \forall wc \end{aligned} \tag{2.19}$$

$$\begin{aligned} &\sum_{wc} \sum_i OENROLL_{wc,i,o} + UNMETOSUT_o = \\ &oreq_o + OVEROSUT_o \ \forall o \end{aligned} \tag{2.20}$$

$$\sum_{wc} AENROLL_{wc,n} + UNMETAIT_n = areq_n + OVERAIT_n \ \forall n \tag{2.21}$$

$$\sum_{w'=wc-blength_i-1}^{wc} bstarth_{w',i} + \sum_{w'=wc-blength_i-1}^{wc} BSTART_{w',i} \leq bavail_i \ \forall wc, i \tag{2.22}$$

$$\sum_{w'=wc-olength_o-1}^{wc} ostarth_{w',i,o} + \sum_{w'=wc-olength_o-1}^{wc} OSTART_{w',i,o} \leq oavail_o \ \forall wc, i, o \tag{2.23}$$

$$\sum_{w'=wc-alength_n+1}^{wc} astarth_{w',n} + \sum_{w'=wc-alength_n+1}^{wc} ASTART_{w',n} \leq aavail_n \ \forall wc, n \tag{2.24}$$

F. DISCUSSION

The objective function, Equation 2.1, of this model seeks to simultaneously satisfy annual Army training requirements, satisfy ODCSPER monthly requirements, minimize the number of soldiers held over, and minimize the variance of each course from its optimal size. By weighting each term, the objective function is converted to units of weeks. There are 50 training weeks in the year. There are typically four weeks in a month. Holdovers are in units of soldier-weeks. A typical course size for AIT is 50 students per course which begins on a weekly basis; likewise 200 is typically the course size for BCT and OSUT. The weights also prioritize competing objectives of the IET schedule. The needs of the Army are the first priority, followed by the need to match capacity to anticipated recruit demand, followed by the need to minimize holdovers and finally provide the best quality of training by filling courses to their predetermined optimal capacities.

Equations 2.2 ensure all recruits are accounted for as *processed* or *not processed* by the end of their first week. Soldiers who arrive at the IET sites, *recruit*, between Monday Midnight and the following Monday Midnight of week $wc - 1$, will either be processed or not subject to the reception battalion capacities. Soldiers who are processed will be available to begin training in week wc. This assumes that soldiers who arrive on Monday morning the last day of week $wc - 1$ will be finished in-processing in time to fill a training company by Thursday evening of week wc. Soldiers who are not processed in week wc are carried forward to week $wc + 1$ and may be processed or not. This provides a means of distinguishing holdover soldiers who have not finished in processing ($NOTPROC$) from holdover soldiers who are available for training, $HOLD$. The first week of the planning horizon must reach back into the last week of the previous fiscal year to carry forward holdover soldiers who have not yet in-processed (*notproch*).

Equations 2.3 separate soldiers who will not be scheduled to attend either OSUT or BCT from the rest of the IET flow in order to schedule them immediately

for AIT or to simply ship them to their permanent duty station. The model does not permit these soldiers to go into holdover status.

Equations 2.4 ensure that in-processing capacity is not exceeded in any week w at any installation, i. Soldiers may not be further assigned until they have completely in-processed.

Equations 2.5 ensure expeditious in-processing for soldiers on a split-option training path. These soldiers will never go unprocessed for a week, ensuring that they are available to begin training at the earliest opportunity. This also provides a convenient model for pulling split option soldiers out of the projected AIT flow on the week following their scheduled graduation from BCT.

Equations 2.6 balance soldiers who have in-processed against available seats for training in the following week. Newly recruited soldiers who are not scheduled for a BCT or OSUT course starting immediately after reception battalion in-processing will be held over until the following week to begin training, $HOLD$. Both recruits entering in week w and recruits in the holdover status (only those who have completed in-processing) generate demand. The start of each FY comes on the heels of summer surge. The first week of the planning horizon must reach back into the last week of the historical fiscal year to carry forward soldiers in holdover status, $holdh$, as well as soldiers who arrived and were in-processed during the last week of the historical fiscal year, $proch$.

Equations 2.7 - 2.9 enforce minimum and maximum BCT company capacities. Modeling divergence from optimal capacity in this manner provides visibility of relative course loads. The same technique is applied to OSUT course capacities using Equations 2.12 - 2.14; and for AIT course capacities using Equations 2.16 - 2.18.

Equations 2.10 balance ODCSPER projected demand for training seats against an equivalent distribution within the IET schedule. Elastic variables, $BMONTHU$ and $BMONTHO$, allow the optimal IET schedule to deviate from the monthly projected demand while the objective function strives to minimize that deviation. The

total number of soldiers enrolled in BCT in any month, m, must be the required number of BCT seats establish by the ODCSPER with as little deviation as possible. Equations 2.15 provides a similar construct for the OSUT course schedules.

Equations 2.11 ensure that split-option trainees have priority in filling BCT courses. This constraint forces enough BCT courses to start to accommodate (at least) the split-option trainees. This model of split-option trainees coincides with the logic used in Equations 2.5, which ensure that split-option trainees are available for training.

Equations 2.19 ensure balanced flow from BCT to AIT. In order to schedule AIT in the first week of the planning horizon we must reach back 10 weeks into the historical fiscal year schedule and carry forward the number of BCT enrollees coinciding with the BCT company starts from that week, *benrollh*. The historical week associated with week one of the planning horizon will always be near the peak of summer surge. That is coincidentally a peak time for split option training enrollment. The number of AIT seats scheduled during any week within the planning horizon must equal the number of BCT enrollees from 10 weeks prior less those who arrived as split-option recruits 11 weeks prior (recall split option trainees are immediately processed and sent to BCT). The number of AIT seats must be further increased to account for recruits in the category of prior service who arrived and were in-processed the previous week. The initial conditions from the historical fiscal year are required to compute this Equations through the eleventh week of the planning horizon, after which the arguments are all variables and data within the current planning horizon for all AIT courses n.

Equations 2.20 balance total number of soldiers projected to start OSUT for all weeks within the planning horizon against the annual required number of soldier starts for each type of OSUT. Elastic variables, $UNMETOSUT$ and $OVEROSUT$, permit a feasible scheduling solution when there are not enough resources throughout the system to accomplish the annual training requirement for each OSUT. Equations

2.21 are similarly constructed for AIT annual requirements.

Equations 2.22 ensure that the number of BCT course starts does not exceed the number of BCT companies available at each installation. BCT companies are modelled as *busy* for eleven-week cycles which include a fill week and a maintenance week. This Equations proposes the typical construct of a BCT company cycle. There are occasions when the maintenance week is eliminated in order to accomplish more starts within the fiscal year, particularly during summer surge. This option may be easily implemented by generating Equations 2.22 as shown for the first 40 weeks of the planning horizon and changing the index for the summation from $wc - 1$ to wc for the final 10 weeks of the planning horizon. Equations 2.23 are constructed similarly for the availability of OSUT companies. Equations 2.24 differ only in that AIT courses do not have the additional fill and maintenance weeks built in resulting in a summation over two fewer weeks.

III. INPUT DATA AND COMPUTATIONAL RESULTS

A. INPUT DATA

The primary source for data was the ATRRS database. ATRRS provides an extensive data base of historical information for every Army Training course. Information for individual training courses is also accessible from the ATRRS web site. However, for obvious reasons, queries for multiple course information are restricted to authorized ATRRS users. TOMA extracted ATRRS reports for all course parameters and loaded the data into EXCEL spreadsheets. ATRRS includes the results of the SMDR; the projected individual training requirements which are used extensively in this model. The SMDR details requirements for other courses not related to enlisted initial training which are beyond the scope of this thesis [Ref. 3]. Only requirements relevant to the IET system were considered. Table I shows a sample of the ATRRS data. Notice the variety in length and capacity among the courses as well as the SMDR annual training requirement for each course. Course lengths are rounded up to the nearest week and entered into the scheduling model. Since all BCT graduations occur on Friday, soldiers may be scheduled to begin training the next Monday. The effect of rounding does not impact the optimality of the schedule since all of the BCT graduations for all installations occur only once per week.

Table II was provided by TOMA. This data was used to parameterize OSUT and BCT courses for FY00. The data provided in this table was more current than what would otherwise be available from ATRRS. Since TOMA manually schedules all OSUT and BCT course starts, they have data that is more current than ATRRS updates.

SCH CD	COURSE NUMBER	PH	TITLE	WKS	DYS	MAX	OPT	MIN	REQMT
91	113-45G10		FIRE CONTROL SYSTEMS REPAIRER	25	2	8	8	4	156
91	610-63G10		FUEL AND ELECTRICAL SYSTEMS RE	12	2	16	12	6	207
91	610-63W10		WHEEL VEHICLE REPAIRER	13	0	40	36	12	1,459
91	611-63Y10		TRACK VEHICLE MECHANIC	11	1	18	15	8	241
91	641-45B10		SMALL ARMS/TOWED ARTILLERY REP	12	2	8	8	4	224
91	642-45D10		SELF-PROPELLED FA TURRET MECHA	8	2	8	6	4	102
91	643-45K10		ARMAMENT REPAIRER	18	2	12	12	6	241

Table I. Examples of ATRRS Input Data

Each course is identified by School Code, Course Number, and Descriptive Title. WKS and DYS describe the course length. The MAX, OPT and MIN columns refer to class capacities in soldiers. The REQMT refers to the objective number of soldiers to begin training in the corresponding course within the FY (the SMDR decision).

FY 00 OSUT and BCT Training Resources

Installation	Reception BN weekly capacity	OSUT CO Total	BCT CO Total	IET CO Total
Fort Jackson	1200	0	40	40
Fort Benning	900		14	40
Infantry OSUT		26		
Fort Sill	900		15	21
Artillery OSUT		6		
Fort Knox	900		10	22
Bradley Scout OSUT		7		
Armor Crewman OSUT		5		
Fort Leonard Wood	900		14	34
Engineer OSUT		7		
Chemical OSUT		4		
MP OSUT		9		
	----	----	----	----
Totals	4800 (soldiers per week)	64	93	157 (companies)

Table II. Available Resources within each BCT and OSUT Installation

Figure 3 illustrates the distribution of annual AIT requirements. Similar courses are aggregated for illustrative purposes only. The total AIT annual training requirement for FY00 is currently 79,773 soldiers.

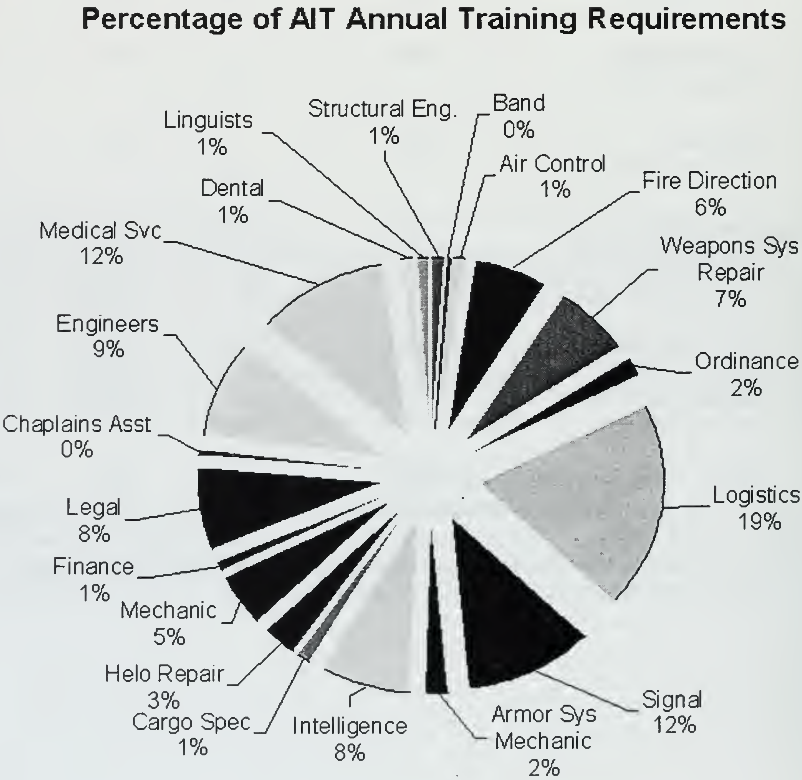

Figure 3. AIT Requirements

Figure 4 illustrates the distribution of annual OSUT requirements. Again, similar courses are aggregated for illustrative purposes. The total OSUT annual training requirement for FY00 is currently 37,156 soldiers.

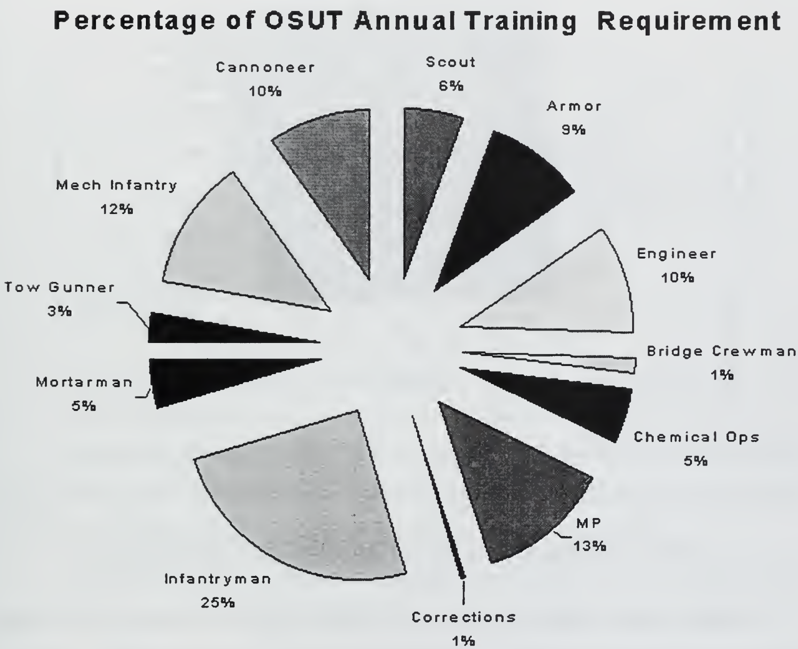

Figure 4. OSUT Requirements

The data regarding projected accessions by category was provided to TOMA by ODCSPER by overhead presentation slides with embedded spreadsheets. ODCSPER uses historical flow patterns to project future accession flow patterns, and ensures annual totals match the SMDR requirements. The decomposition of projected accessions by category is telling. Figure 5 shows the projected flow of accessions through the

reception battalions. Recall every soldier regardless of category must in-process. Notice the discontinuous surge in June to nearly 18,000 arrivals in one month across all installations. This seems to be due primarily to soldiers doing split-option training. The flow is fairly constant otherwise.

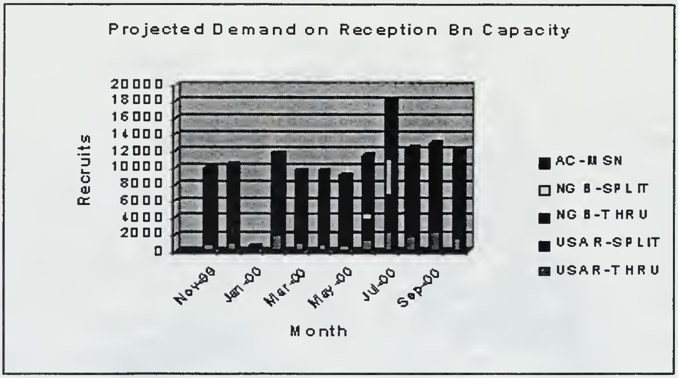

Figure 5. Aggregate Demand for Reception Battalion Resources

Figure 6 illustrates that the summer surge peak of BCT demand is not nearly so dramatic, but clearly evident. Each course is provided resources (budget, personnel etc.) to accommodate their annual training requirement assuming a level flow of trainees, even though resource managers and proponent schools alike realize the flow of trainees will fluctuate. It is no surprise that the June spike of trainees shown in Figure 6 increases the complexity of scheduling not only from a resource perspective but also from a planning perspective. The planner must project the level of each installation's hold over account by week until the entire summer surge of recruits are enrolled in training. For this year and next that means projecting hold overs into the

following FY and attempting to optimally schedule courses so as to minimize total hold over time.

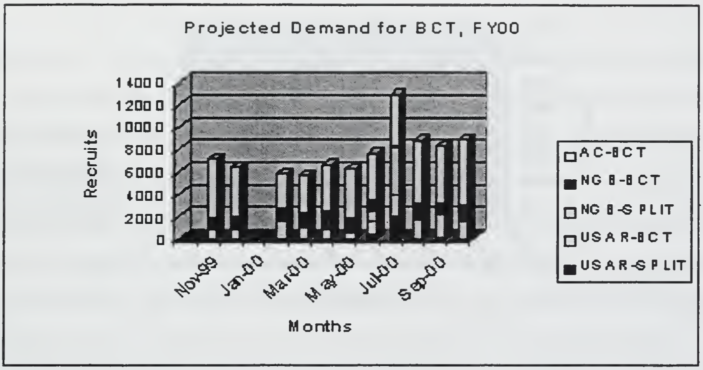

Figure 6. Aggregate Demand for Basic Combat Training Resources

Intuitively, one would expect the subsequent AIT to have a comparably dramatic peak. However, Figure 7 shows that the flow remains relatively level, compared to BCT, with split-option trainees removed from the flow after BCT.

Figure 8 reveals a bi-modal demand for OSUT across the planning horizon rather than a flow dominated by summer surge as with BCT, shown in Figure 6.

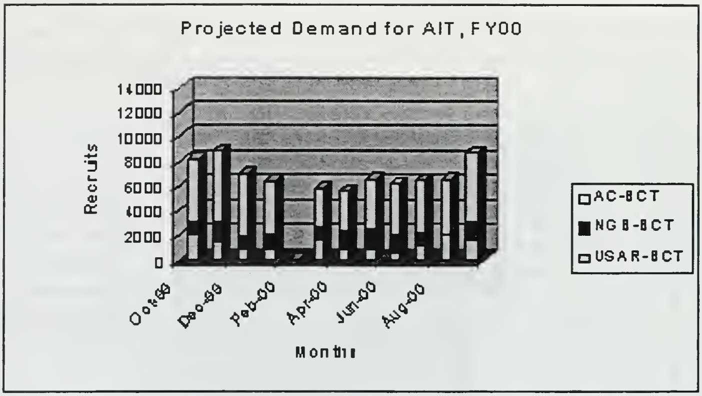

Figure 7. Aggregate Demand for AIT

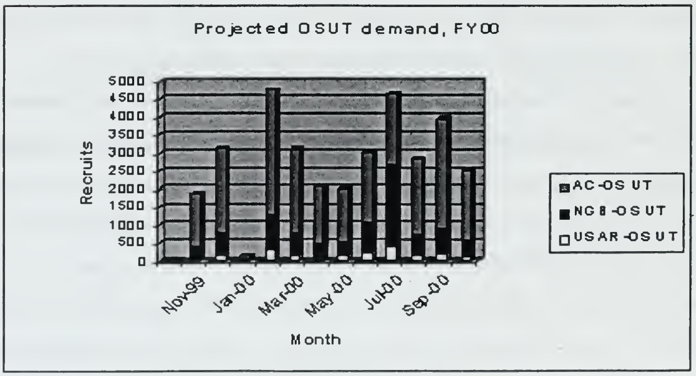

Figure 8. Aggregate Demand for OSUT

B. RESULTS SUMMARY

Members of TOMA, the activity responsible for IET scheduling, knew before this study began that the requirements for the IET schedule exceeded available resources. Even if there were sufficient resources to satisfy all of the competing demands of the system, developing a feasible solution using manual methods is a non-trivial task. Combinatorially the size of this problem is astronomical. It is through the will, creativity and historical institutional knowledge of the civil servant schedulers that current scheduling methods work as well as they do. It can not be overstated that the ability of a seasoned human scheduler to make decisions that *make sense* is nearly impossible to replicate using an automated system. Even this optimization model is suspect until validated and refined by the people who are responsible for this schedule every day.

For FY00, TOMA anticipates a shortfall of over 50 BCT companies during the summer surge. Anticipated accomplishment of SMDR requirements is equally grim. The inability to entirely satisfy any one of the measures of performance presented in this thesis, let alone all of them, continues to frustrate schedulers. Beyond scheduling issues, the logistical consequences project additional burden the already strained system. Realizing that resource constraints will continue to be a reality for the foreseeable future, the Director of TOMA was careful to pose the problem such that the solution would be in terms of the best use of available resources rather than in terms of resource shortfalls and an additional requirements wish list. The model developed in this thesis minimizes mission not accomplished (in weeks). Performance is measured by achievement of annual training requirements, variability between seat capacity and projected demand, holdover weeks and course load levels.

The MIP scheduling model solved for the optimal mixed integer solution on an WINTEL Pentium III personal computer with 190 megabytes (meg) of random access memory (RAM) in approximately 9 hours. The MIP contains 116,789 constraints and 44,000 variables. The optimal solution yields a schedule which accomplishes 94

percent of the FY00 annual training requirements. The schedule has a 12 percent mismatch between types of training seats scheduled by month (BCT and OSUT) versus anticipated demand for training by type (13,765 seats out of 119,502 mismatched), with an overall shortage of training seats from projected demand for BCT and OSUT for FY00 of 6,475 seats. This is an improvement from a projected shortage of over 12,000 seats. Optimizing the training schedule creates an additional 5,500 seats for recruiters. The optimal solution results in 90,360 weeks that soldiers will spend in a holdover status. This represents an improvement of about 90,000 soldier weeks that would be spent spent in holdover status using current scheduling methods. That is 1800 years of soldier's time, or a brigade worth of manpower for the Army at no additional cost.

1. SMDR Annual Training Requirements

Optimal scheduling of courses which vary by size, length, and location results in a schedule that accomplishes 94 percent of the SMDR requirements. Figure 9 aggregates these results by school. This result provides global insight not readily available using the ATRRS data base. In this model, soldier flow through the entire IET system results in zero-sum accountability of each soldier input and his or her utilization of resources in each week of the planning horizon. Therefore, each scheduled training seat results from a path of allocated resources across the dimensions of location and time (and several command authorities). This schedule will provide decision makers with the confidence that each school has appropriately scheduled enough training to accomplish their annual requirement, and that the combination of schedules among schools will not result in bottlenecks at reception battalions and scheduling mismatches among sequential training courses. Appendices A and B provide a summary of the annual scheduling result for each AIT course and OSUT course, respectively.

It is an interesting result that OSUT training schedules fare worse than AIT. The current methodology schedules all OSUT courses first based on ODCSPER pro-

jections. Scheduling OSUT is certainly the least complicated program of training to schedule, so it is natural that it would be done first. However, the variable size and length of lower density AIT courses appear to require a steady stream of recruits out of BCT to make the best utilization of each course and ultimately maximize the achievement of annual requirements. That is a complicated way of saying BCTs provide a bigger bang for the buck by facilitating multiple AIT course starts following each BCT graduation. It is possible that multiple optimal solutions exist, or solutions whose objective function value are very close. Adding constraints for unique FY scheduling issues can be done with little effort and then the model may be rerun. For example, constraint equations could be quickly added to level the unmet requirements among all courses, or perhaps prioritize the fill of courses for Army critical shortages.

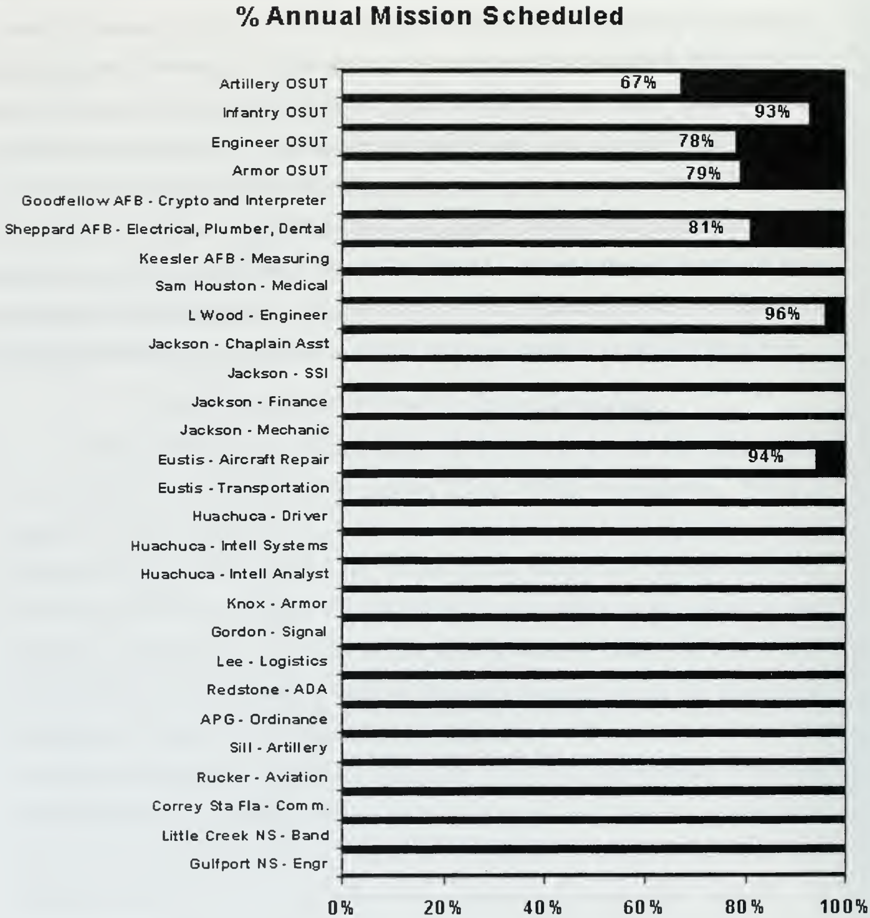

Figure 9. Percentage of Annual Training Requirements Scheduled as a result of the FY00 Optimal Scheduling Solution

2. Capacity Versus Recruit Demand

Figure 10 illustrates the divergence of the optimal schedule from ODCSPER projected recruit demand by month. These deviations may be compared with ODCSPER requirements presented in Figure 6. The schedule comes close in the first half of the year and then deteriorates significantly during the summer surge. However, this information provides planners some insight on where it may be possible to redistribute some of the training requirements. For example, notice the distribution of mismatched seats for March in Figure 10. Notice that in March there is a balance between BCT seats exceeding ODCSPER requirements and OSUT seats which are fewer that ODCSPER requirements. This happens because while failing to achieve one measure of performance, match capacity to demand, the program is able to achieve two others, annual requirements and avoid hold overs. Since the projected demand is based on historical demand, the true demand is unknown. In fact, the true demand is ultimately driven by the training schedule that TRADOC proponent schools enter into ATRRS. This is because the ATRRS data gets ported into the *Request* system which provides MOS choices to potential recruits. Therefore, it may be possible to redistribute the requirements somewhat. The net result would be that recruiters would simply offer March accessions (recruits who come in the MEP door in February) more MOSs with BCT-AIT paths and fewer MOSs with OSUT paths. This would result in a more efficient use of the training system resources. Furthermore, Figure 10 provides decision makers with qualitative information about the parity (or lack of) between available resources and mission guidance.

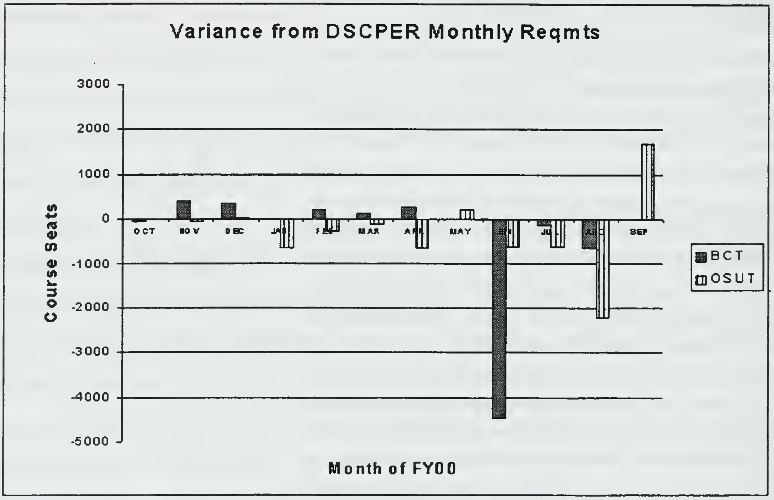

Figure 10. Schedule Deviation from Projected Recruit Demand as a result of the FY00 Optimal Scheduling Solution

3. Scheduled Hold Overs

Certainly the most desirable state of the training system would be to have no soldier time wasted in a hold over status. It is undesirable to have soldiers stagnate in the training system. However, there are considerations beyond the scope of this thesis related to FY appropriations, manpower budgeting, and recruit incentives. These considerations arguably illustrate competing tradeoffs resulting in soldier hold overs at the end of the FY. Figure 11 shows the distribution of 90,360 hold over weeks FY00 resulting from the optimal schedule. This is actually quite an improvement from what was expected. A shortfall of more than 50 BCT companies translates to about 12,000 soldiers in hold status for the duration of summer surge, 12 to 15 weeks, or up to 180,000 hold over weeks. An improvement of 90,000 hold weeks saves 1800 soldier years. *That is a brigades' worth of manpower for the Army without any additional resources.*

The resolution of the data generated by this model provides decision makers with a planning tool for the projected surge. Figure 12 shows the distribution of holdovers by installation during the summer surge period. Notice that the remaining holdovers tend to be pre-positioned at the installations with annual training requirement shortfalls. The subsequent FY will have to accommodate the remaining holdovers and unmet training requirements. This model automatically generates output that can be used as input to model the following FY.

In addition to the hold accounts illustrated, another by product of this model are variables to illustrate the processing flow through each reception battalion by week. This schedule resulted in a distribution of recruits to each installation in each week that was below each reception battalion's weekly capacity. The result is that for this solution, there were no soldiers who were allocated to the not processed hold state, $NOTPROC$, at any installation. Surprisingly, all soldiers that were held over were held over due to lack of availability of training course starts, not due to constrained reception battalion capacity.

Figure 11. Scheduled Holdovers
as a result of the FY00 Optimal Scheduling Solution

4. Deviations From Optimal Course Size

The test case, FY00, provided little insight concerning course levels. An unsurprising result is that courses are scheduled at their maximum capacity during summer surge and vary about the predetermined *optimal* course size elsewhere throughout the year. The number of seats scheduled for each course throughout the planning horizon was within its minimum and maximum capacity range. The previous three measures of effectiveness significantly outweighed optimal course size for scheduling impact.

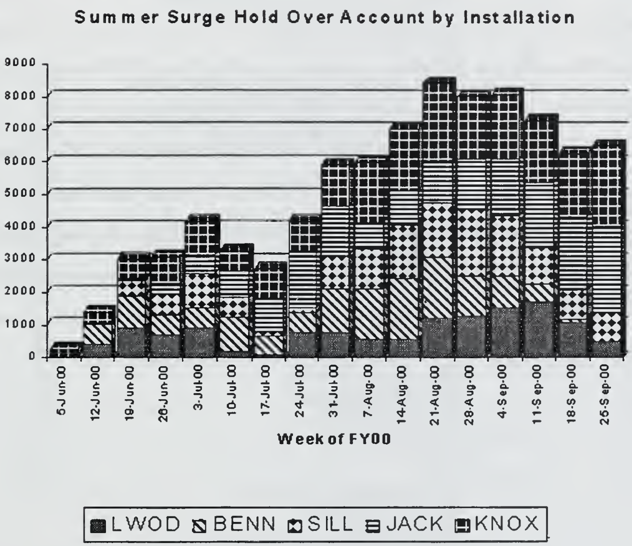

Figure 12. Summer Holdovers by Installation as a result of the FY00 Optimal Scheduling Solution

5. Schedules

Schedules for all IET courses (BCT, AIT and OSUT) were created by this model. The schedules are matrices of course titles to weeks providing the number of course starts ($OSTART$, $BSTART$, $ASTART$) and the corresponding number of seats scheduled ($OENROLL$, $BENROLL$, $AENROLL$). Additionally, the model provides the reception battalion flow, pursuant to the optimal schedule. This results in matrices of reception battalions to weeks providing the flow of soldiers scheduled to in-process ($PROC$, and $PROC2$) and holdovers ($HOLD$, and $NOTPROC$). The summary of the optimal scheduling solution for BCT at all 5 installations and AIT for 24 schools are presented in Figures 13 and 14, respectively. Notice the load over 24 schools of AIT in each week of FY00 closely agrees with the BCT course schedule over 5 installations for each week of FY00 with a 10 week time lag. This illustrates the fundamental accomplishment of this thesis which balances the number of BCT graduates with the subsequent AIT skill producing schools. Aggregate differences are a result of split option and prior service trainees who take atypical routes through the IET system. OSUT schedules are summarized in Figure 15.

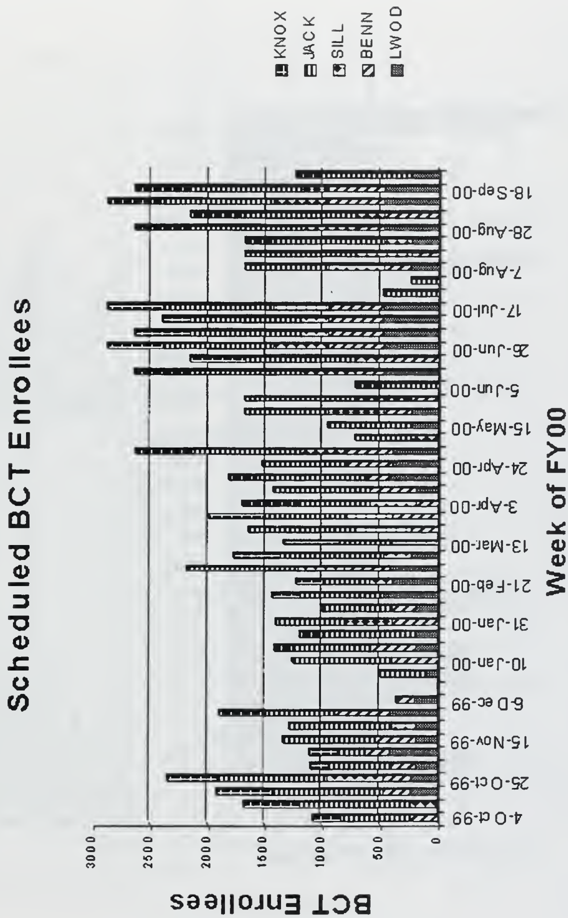

Figure 13. Scheduled BCT Enrollment
BCT scheduled starts (soldiers) from the optimal solution, FY00, across all five BCT installations

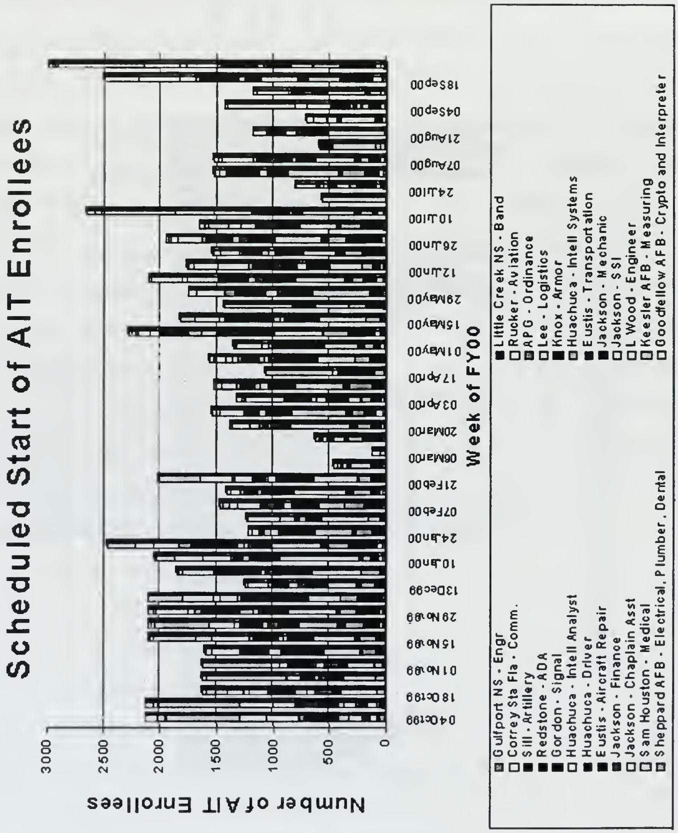

Figure 14. Scheduled AIT Enrollment
AIT scheduled starts (soldiers) from the optimal solution, FY00, across all 24 AIT schools

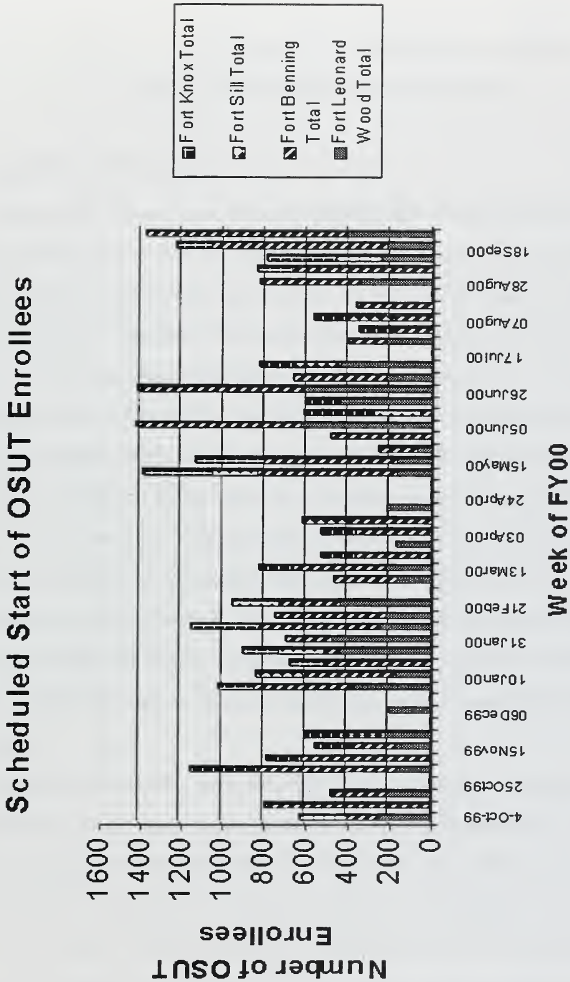

Figure 15. Scheduled OSUT Enrollment
OSUT scheduled starts (soldiers) from the optimal solution, FY00, across all five OSUT installations

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This model provides an optimal integer solution representing the combination of course starts for the entire IET system across a one-year planning horizon that will most efficiently and effectively accomplish the Structure Manning Decision Review annual training requirements. The results for FY00 illustrate that by optimizing the training schedule the Army could have an additional brigade's worth of manpower at no additional cost. This model can feasibly schedule over 5500 more seats for IET training than manual methods. Optimal scheduling saves 90,000 weeks or 1800 soldier years that are projected to be spent in a holdover status during FY00. This model guarantees that scheduled training seats are allocated prerequesite training seats and in-processing capacity, as applicable, such that each soldier can feasibly arrive to his or her scheduled training seat. It eliminates mismatches that arise between BCT and AIT using manual scheduling methods. This model suggests better uses of Army resources, enabling recruiters, trainers and Army units to more effectively accomplish their missions.

This model can easily accommodate policy changes or additional constraints. This model has enough resolution to provide interesting answers to "what-if" analyses. It allows exploration of the effect of varying course capacities, resource levels, or course duration on optimality. It allows TRADOC to quantify, well into the future, the impact of SMDR decisions relative to resource levels. This model could be used to explore the utility of the current resourcing policy which allocates resources under the assumption of level trainee flow.

This model may be run using a spreadsheet interface. A spreadsheet interface would enable the user to easily input and update data. The primary drawback to this model, as with other scheduling methods, is its dependence on ATRRS input,

whose collection can be time consuming and difficult. All of the data is not readily available from ATRRS. Scheduling decisions from the prior fiscal year are required to generate the training schedule for the current planning year. ATRRS does not currently provide historical course schedule information in a matrix format that can be easily interfaced using a spreadsheet.

B. RECOMMENDATIONS

TRADOC should implement this model to aid, but not replace, the decision maker. The implementation requires a computer with a Pentium III processor, 200 MB of random access memory, GAMS and the CPLEX solver. Further development of the spreadsheet interface will allow the execution of the GAMS program from within EXCEL. An ATRRS interface which provides a method to query the ATRRS database directly and format a report for the model's input data would enhance the usability of this model. Such an algorithm would require only a short series of looping commands to generate input data by school code and course number. This would simplify updating the data repeatedly as the requirements and resources adjust throughout the training year. This would create a very powerful tool with a familiar interface that could be repeatedly executed by TOMA.

C. FURTHER RESEARCH

This model recommends number of soldiers and course starts based on a specific objective function. The objective function of the model could be easily changed to explore scheduling goals different from, or in addition to, the measures of performance described in this thesis. The model's current framework lends itself to further development including number of beds per soldier, barracks per course, aircraft per trainee, and other resource constraints. Interesting follow-on research would be to assist each school to produce high resolution models to use for their own scheduling requirements. Binding constraints found in models which encompass each school's

total training mission requirements could be implemented in this TRADOC level model to increase the resolution of the model and visibility of the impact on the entire system. Attrition data is not built into the model because the *Request* system is designed to account for attrition coefficients associated with DEP loss by overbooking seats scheduled in the ATRRS system. Further analysis of the effect and reliability of attrition coefficients could improve the ability of this model to represent the training system. Finally, the projected flow of recruits in this model is deterministic. Stochastic methods which account for economic conditions, recruit profile or geographic location could enhance this model's representation of anticipated inputs to the system.

APPENDIX A. AIT FY00 SUMMARY

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
A-710-0010	STRUCTURES (51B10)	835	835	100%
433-F2	ENGINEER DIVER MOS 00B10 PHASE	39	39	100%
052A Total	052A Total	874	874	100%
450-02B10	CORNET/TRUMPET	27	27	100%
450-02C10	BARITONE/EUPHONIUM	11	11	100%
450-02D10	FRENCH HORN	14	14	100%
450-02E10	TROMBONE	18	18	100%
450-02F10	TUBA	17	17	100%
450-02G10	FLUTE/PICCOLO	14	14	100%
450-02H10	OBOE	7	7	100%
450-02J10	CLARINET	26	26	100%
450-02K10	BASSOON	5	5	100%
450-02L10	SAXOPHONE	19	19	100%
450-02M10	PERCUSSION	13	13	100%
450-02N10	PIANO	14	14	100%
450-02T10	GUITAR	5	5	100%
450-02U10	ELECTRIC BASS GUITAR PLAYER	5	5	100%
514 Total	514 Total	195	195	100%
A-231-0450	COMM SIGNALS COLLECTION & PROC	89	89	100%
891 Total	891 Total	89	89	100%
222-93C10	AIR TRAFFIC CONTROL OPERATOR	289	289	100%
556-93P10	AVIATION OPERATIONS SPECIALIST	401	401	100%
600-67N10	UH-1 HELICOPTER REPAIRER	119	119	100%
600-67V10 (OH-58)	OBSERVATION/SCOUT HELICOPTER R	37	37	100%
11 Total	11 Total	846	846	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
042-13M10 (F)	TATS MULTIPLE LAUNCH ROCKET SY	1053	1053	100%
043-13P10 (F)	TATS MLRS FIRE DIRECTION SPEC	407	407	100%
043-13P10 (F) (DL)	TATS MLRS FIRE DIRECTION SPECI	66	66	100%
043-13P10 (F) (DL)	TATS MLRS FIRE DIRECTION SPECI	0	0	NA
104-35C10	SURVEILLANCE RADAR REPAIRER	23	23	100%
121-35M10	RADAR REPAIRER	95	95	100%
221-13R10 (F)	FIELD ARTILLERY FIREFINDER RAD	174	174	100%
221-13R10 (F) (DL)	TATS FIELD ARTILLERY FIRE FIND	21	21	100%
221-13R10 (F) (DL)	TATS FIELD ARTILLERY FIRE FIND	29	29	100%
250-13C10 (F)	AUTOMATED FIRE SPT SYSTEMS SPE	130	130	100%
250-13C10 (F) (DL)	TATS FIRE SPT AUTOMATED SYS OP	30	30	100%
250-13C10 (F) (DL)	TATS FIRE SPT AUTOMATED SYS OP	21	21	100%
250-13D10 (F)	TATS FA ARTILLERY TACT DATA SY	0	0	NA
250-13E10 (F)	TATS CANNON FIRE DIRECTION SPE	952	952	100%
250-13E10 (F) (DL)	TATS CANNON FIRE DIRECTION SPE	15	15	100%
250-13E10 (F) (DL)	TATS CANNON FIRE DIRECTION SPE	12	10	120%
250-13F10 (F)	TATS FIRE SUPPORT SPECIALIST	1262	1262	100%
250-13F10 (F) (DL)	TATS FIRE SUPPORT SPECIALIST	368	368	100%
250-13F10 (F) (DL)	TATS FIRE SUPPORT SPECIALIST	0	0	NA
412-82C10 (F)	TATS FIELD ARTILLERY SURVEYOR	233	233	100%
412-82C10 (F) (DL)	TATS FIELD ARTILLERY SURVEYOR	103	103	100%
412-82C10 (F) (DL)	TATS FIELD ARTILLERY SURVEYOR	24	25	96%
420-93F10 (F)	TATS FA METEOROLOGICAL CREWMEM	100	100	100%
420-93F10 (F) (DL)	TATS FA METEOROLOGICAL CREWMEM	26	26	100%
420-93F10 (F) (DL)	TATS FA METEOROLOGICAL CREWMEM	26	26	100%
61 Total	61 Total	5170	5169	100%
113-45G10	FIRE CONTROL SYSTEMS REPAIRER	156	156	100%
610-63G10	FUEL AND ELECTRICAL SYSTEMS RE	207	207	100%
610-63W10	WHEEL VEHICLE REPAIRER	1459	1459	100%
611-63Y10	TRACK VEHICLE MECHANIC	240	241	100%
641-45B10	SMALL ARMS/TOWED ARTILLERY REP	224	224	100%
642-45D10	SELF-PROPELLED FA TURRET MECHA	102	102	100%
643-45K10	ARMAMENT REPAIRER	241	241	100%
662-52C10	UTILITIES EQUIPMENT REPAIRER	483	483	100%
662-52D10	POWER GENERATION EQUIPMENT REP	1293	1293	100%
690-63J10	QUARTERMASTER/CHEMICAL EQUIPME	495	495	100%
702-44E10	MACHINIST	141	141	100%
704-44B10	METAL WORKER	499	499	100%
91 Total	91 Total	5540	5541	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
121-27E10	LAND COMBAT ELEC MISSILE SYS R	155	155	100%
121-27E10-RC	LAND COMBAT ELEC MISSILE SYSTE	4	1	400%
121-27M10	MULTIPLE LAUNCH ROCKET SYSTEM	101	101	100%
121-27T10	AVENGER SYSTEM REPAIRER	79	79	100%
121-35B10	LAND COMBAT SUPPORT SYSTEM TES	18	18	100%
198-35Y10	INTEGRATED FAMILY TEST EQUIPME	97	97	100%
198-39B10	AUTOMATIC TEST EQUIPMENT OPERA	33	33	100%
4E-91E/431-55D10/20	EXPLOSIVE ORDNANCE DISPOSAL SP	164	164	100%
645-55B10	AMMUNITION SPECIALIST	753	753	100%
645-55B10-RC	AMMUNITION SPECIALIST-RC	25	25	100%
93 Total	93 Total	1429	1426	100%
491-77L10	PETROLEUM LABORATORY SPECIALIS	103	103	100%
492-92M10	MORTUARY AFFAIRS SPECIALIST	160	160	100%
551-92A10	AUTOMATED LOGISTICAL SPECIALIS	3420	3420	100%
552-92Y10	UNIT SUPPLY SPECIALIST	3065	3065	100%
720-77W10	WATER TREATMENT SPECIALIST	431	431	100%
760-43M10	FABRIC REPAIR SPECIALIST	256	256	100%
800-92G10	FOOD SERVICE SPECIALIST	4160	4160	100%
821-77F10	PETROLEUM SUPPLY SPECIALIST	2881	2881	100%
840-57E10	LAUNDRY AND SHOWER SPECIALIST	464	464	100%
860-92R10	PARACHUTE RIGGER	505	505	100%
101 Total	101 Total	15445	15445	100%
101-31P10	MICROWAVE SYSTEMS OPERATOR/MAI	317	317	100%
101-31U10	SIGNAL SUPPORT SYSTEMS SPECIAL	1971	1971	100%
101-35E10	RADIO/COMSEC REPAIRER	518	518	100%
102-31S10	SATCOM SYSTEMS OPERATOR/MAINTA	227	227	100%
102-35D10	ATC SYSTEMS, SUBSYSTEMS & EQUI	57	57	100%
102-35L10	AVIONIC COMMUNICATIONS EQUIPME	93	93	100%
102-35Q10	AVIONIC FLIGHT SYSTEMS REPAIRE	50	50	100%
102-35R10	AVIONIC RADAR REPAIRER	98	98	100%
150-74G10	TELECOMMUNICATIONS COMPUTER OP	72	72	100%
160-35J10	COMPUTER/AUTOMATION SYSTEMS RE	165	165	100%
198-35F10	SPECIAL ELECTRONIC DEVICES REP	132	133	99%
201-31C10	TATS RADIO OPERATOR-MAINTAINER	823	823	100%
202-31R10 (CT) (F)	TATS MULTICHANNEL TRANSMISSION	1663	1663	100%
260-31F10 (CT) (F)	TATS ELECTRONIC SWITCHING SYS	1000	1031	97%
260-74C10	RECORD TELECOMMUNICATIONS OPER	599	599	100%
531-74B10	INFORMATION SYSTEMS OPERATOR-A	566	566	100%
621-31L10 (F)	TATS CABLE SYSTEMS INSTALLER-M	687	687	100%
622-35N10	WIRE SYSTEMS EQUIPMENT REPAIRE	156	156	100%
113 Total	113 Total	9194	9226	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
611-63E10	M1 ABRAMS TANK SYSTEMS MECHANI	407	407	100%
611-63T10	M2/3 BRADLEY FIGHTING VEHICLE	730	730	100%
643-45E10	M1A1 ABRAMS TANK TURRET MECHAN	222	222	100%
643-45T10	BRADLEY FIGHTING VEHICLE SYS T	174	174	100%
171 Total	171 Total	1533	1533	100%
233-96H10	IMAGERY COMMON GROUND STATION	129	129	100%
241-97E10	INTERROGATOR	134	134	100%
242-96D10	IMAGERY ANALYST	192	192	100%
243-96B10	INTELLIGENCE ANALYST	936	936	100%
243-96R10	GROUND SURVEILLANCE SYSTEMS OP	243	243	100%
244-97B10	COUNTERINTELLIGENCE AGENT	261	261	100%
244-97L10-RC	TRANSLATOR/INTERPRETER-RC	25	25	100%
301 Total	301 Total	1920	1920	100%
102-33W10	EW/INTERCEPT SYSTEMS REPAIRER	292	292	100%
231-98H10	MORSE INTERCEPTOR	816	816	100%
232-98C10	SIGNALS INTELLIGENCE ANALYST	374	374	100%
233-98J10	ELECTRONIC INTELLIGENCE INTERC	176	176	100%
301 Total	301 Total	1658	1658	100%
043-14J10	ADA C4I TACTICAL OPER CTR ENH	243	243	100%
043-14M10	MAN-PORTABLE AIR DEFENSE SYSTE	161	161	100%
043-14R10	BRADLEY LINEBACKER CREWMEMBER	396	396	100%
043-14S10	AVENGER CREWMEMBER	903	903	100%
043-14T10	PATRIOT LAUNCHING STATION ENHA	515	515	100%
811-88M10	MOTOR TRANSPORT OPERATOR	602	601	100%
811-88M10 (RECLASS)	MOTOR TRANSPORT OPERATOR (RECL	0	0	NA
441 Total	441 Total	2820	2819	100%
062-88K10	WATERCRAFT OPERATOR	174	174	100%
690-88P10-RC	RAILWAY EQUIPMENT REPAIRER-RC	12	12	100%
812-88U10-RC	RAILWAY OPERATAIONS CREWMEMBER	18	18	100%
822-88H10	CARGO SPECIALIST	536	536	100%
850-88T10-RC	RAILWAY SECTION REPAIRER-RC	16	16	100%
551 Total	551 Total	756	756	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
102-68J10 (AH-1F)	AH-1F ARMAMENT/MISSILE SYSTEMS	48	48	100%
102-68J10 (OH-58D)	OH-58D ARMAMENT/ELECTRICAL SYS	140	140	100%
102-68N10	AVIONIC MECHANIC	225	225	100%
600-67T10	UH-60 HELICOPTER REPAIRER	632	779	81%
600-67U10	CH-47 HELICOPTER REPAIRER	346	346	100%
600-67Y10	AH-1 ATTACK HELICOPTER REPAIRE	40	40	100%
601-68B10	AIRCRAFT POWERPLANT REPAIRER	154	154	100%
602-68D10	AIRCRAFT POWERTRAIN REPAIRER	121	121	100%
602-68F10	AIRCRAFT ELECTRICIAN	163	163	100%
603-68G10	AIRCRAFT STRUCTURAL REPAIRER	148	148	100%
646-68X10 (AH-64A)	AH-64A ARMAMENT/ELECTRICAL SYS	221	221	100%
646-68Y10	AH-64D ARMAMENT/ELECTRICAL/AVI	65	65	100%
552 Total	552 Total	2303	2450	94%
610-63B10	LIGHT WHEEL VEHICLE MECHANIC	2802	2802	100%
610-63S10	HEAVY WHEEL VEHICLE MECHANIC	1196	1196	100%
805 Total	805 Total	3998	3998	100%
541-73D10 (F)	TATS ACCOUNTING SPECIALIST	223	223	100%
542-73C10(F)	TATS FINANCE SPECIALIST	590	590	100%
805A Total	805A Total	813	813	100%
500-75B10 (F)	TATS PERSONNEL ADMINISTRATION	1456	1456	100%
500-75F10 (F)	TATS PERS INFO SYS MGT SPECIAL	220	220	100%
500-75H10	PERSONNEL SERVICES SPECIALIST	1309	1309	100%
510-71L10 (F)	TATS ADMINISTRATIVE SPECIALIST	2833	2833	100%
512-71D10	LEGAL SPECIALIST	391	391	100%
512-71D10-RC	LEGAL SPECIALIST-RC	21	21	100%
805C Total	805C Total	6230	6230	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
561-71M10	CHAPLAIN ASSISTANT	303	303	100%
805D Total	805D Total	303	303	100%
413-51T10	TECHNICAL ENGINEERING SPECIALI	226	226	100%
612-62B10	ENGINEER EQUIPMENT REPAIRER	1196	1196	100%
713-62E10	HEAVY CONSTRUCTION EQUIPMENT O	760	890	85%
713-62F10	CRANE OPERATOR	204	204	100%
713-62G10	QUARRYING SPECIALIST	80	80	100%
713-62H10	CONCRETE AND ASPHALT EQUIPMENT	88	88	100%
713-62J10	GENERAL CONSTRUCTION EQUIPMENT	532	532	100%
721-51R10	INTERIOR ELECTRICIAN	204	248	82%
811-88M10	MOTOR TRANSPORT OPERATOR	3780	3864	98%
807 Total	807 Total	7070	7328	96%
300-91B10	MEDICAL SPECIALIST	6956	6956	100%
302-91X10	MENTAL HEALTH SPECIALIST (MHS)	250	250	100%
312-91Q10	PHARMACY SPECIALIST	199	199	100%
321-91R10	VETERINARY FOOD INSP SP (BASIC	176	176	100%
321-91R10(RC)	VET FOOD INSPECTION SP (BASIC)	12	12	100%
321-91T10	ANIMAL CARE SPECIALIST	90	90	100%
322-91S10	PREVENTIVE MEDICINE SPECIALIST	166	166	100%
322-91S10(RC)	PREVENTIVE MEDICINE SPEC (RC)	10	10	100%
513-71G10	PATIENT ADMIN SPECIALIST	414	414	100%
513-71G10(RC)	PATIENT ADMIN SPECIALIST (RC)	55	55	100%
551-76J10	MEDICAL SUPPLY SPECIALIST	517	517	100%
551-76J10(RC)	MEDICAL SUPPLY SPECIALIST (RC)	57	57	100%
800-91M10	HOSP FOOD SVC SPECIALIST (BASI	359	359	100%
800-91M10(RC)	HOSP FOOD SVC SP (BASIC)(RC)	9	9	100%
81 Total	81 Total	9270	9270	100%
E3ABR2P031 010	PRECISION MEASURING EQUIPMENT	70	70	100%
881 Total	881 Total	70	70	100%
J3ABR2A635 000	APPRENTICE ACFT PNEUDRAULIC SY	79	79	100%
J3ABR3E031 003	ELECTRIC POWER LINE SPECIALIST	23	23	100%
J3ABR3E431 007	PLUMBER/UTILITIESMAN (51K10)	137	137	100%
330-91E10	DENTAL SPECIALIST	230	400	58%
4B-F2/198-91A10	MEDICAL EQUIP REPAIRER (UNIT L	245	245	100%
883 Total	883 Total	714	884	81%
X3ABR1N330 001	APR CRYPTOLOGIC LINGUIST SPC(N	51	51	100%
X3ABR1N332A 013	VOICE INTERCEPTOR (SPANISH) (9	73	73	100%

	AIT Course	Optimal Schedule	ANNREQMT	% SMDR
X3ABR1N333A 013	VOICE INTERCEPTOR (RUSSIAN) (9	253	253	100%
X3ABR1N334A 009	VOICE INTERCEPTOR (CHINESE) (9	50	50	100%
X3ABR1N334B 004	VOICE INTERCEPTOR (VIETNAMESE)	10	10	100%
X3ABR1N334G 014	VOICE INTERCEPTOR (KOREA) (98G	143	143	100%
X3ABR1N335A 021	VOICE INTERCEPTOR (ARABIC) (98	209	209	100%
X3ABR1N335C 004	VOICE INTERCEPTOR (HEBREW) (98	4	4	100%
X3ABR1N335D 000	VOICE INTERCEPTOR (PERSIAN FAR	52	52	100%
X3ABR3E731 007	FIRE PROTECTION APPRENTICE (51	85	85	100%
885 Total	885 Total	930	930	100%
Total AIT Seats		**79170**	**79773**	**99%**

APPENDIX B. OSUT FYOO SUMMARY

	OSUT Course	Optimal Schedule	ANNREQMT	% SMDR
19D10-OSUT (M3)	M3 BRADLEY/CFV CAVALRY SCOUT	1650	2110	78%
19K10-OSUT	M1/M1A1 ABRAMS ARMOR CREWMAN	2805	3528	80%
	Fort Knox Total	4455	5638	79%
12B10-OSUT	COMBAT ENGINEER	3230	3811	85%
12C10-OSUT	BRIDGE CREWMAN	504	529	95%
54B10-OSUT	CHEMICAL OPERATIONS SPECIALIST	1299	2025	64%
95B10-OSUT	MILITARY POLICE	3515	4880	72%
	Fort Leonard Wood Total	8548	11245	76%
11B10-OSUT	INFANTRYMAN	6980	7548	92%
11B10-OSUT (ASIC2)	DRAGON GUNNER	505	505	100%
11B10-OSUT (ST)	INFANTRYMAN	1080	1128	96%
11C10-OSUT	INDIRECT FIRE INFANTRYMAN	1648	1838	90%
11H10-OSUT	HEAVY ANTIARMOR WEAPONS INFANT	1042	1042	100%
11M10-OSUT	FIGHTING VEHICLE INFANTRYMAN	4320	4616	94%
	Fort Benning Total	15575	16677	93%
13B10-OSUT	CANNON CREWMEMBER	2420	3595	67%
	Fort Sill Total	2420	3595	67%
Total OSUT Seats		**30998**	**37155**	**83%**

LIST OF REFERENCES

[1] *Army Regulation 350-10, Management of Army Individual Training Requirements and Resources*, Effective 15 October 1990, Department of the Army, 1990.

[2] Army Command, *Leadership and Management: Theory and Practice*, US Army War College, Carlisle Barracks, 1992-1993.

[3] Army Training Requirements and Resources System. *ATRRS Home Page.*, [Online]. Available: WWW URL: http://www.asmr.com/atrrs/default.asp. 15 May 1999.

[4] Brooke, A.,D. Kendrick, and A. Meeraws, *GAMS: A User's Guide, Release 2.25*, GAMS Development Corporation, Washington D. C., 1996.

[5] Ward, Stephen C., "How to Computerize your Personnel Planning," *Long Range Planning*, Vol. 20, No. 4, 1987, pp. 88-101.

[6] Burns, R. N. and G. J. Koop, "Modular Approach to Optimal Multiple Shift Manpower Scheduling," *Operations Research*, Vol. 35, 1 January- February 1987, pp. 100-110.

[7] Sklar, Michael G., "Heuristics for scheduling aircraft and crew during airlift operations," *Transportations Science*, Vol. 24, 1 February 1990, pp. 63-76.

[8] Chilson, Clay S., *Minimizing Army Cadet Temporary Duty*, Master's Thesis, Monterey, March 1998.

[9] Ignizio, James P., "An Algorithm for the Scheduling of Army Battalion Training Exercises," *Computer Operations Research*, Vol. 14, No. 6, 1987, pp. 479-491.

[10] McGinnis, Michael L., *Resource Scheduling for the United States Army's Basic Combat Training Program*, Doctor of Philosophy Thesis, University of Arizona, Tucson, 1994.

[11] Samms, F., *Scheduling of Courses at a Naval Training Facility*, Master's Thesis, Naval Postgraduate School, Monterey, September 1973.

[12] Holloran, Thomas J. and Judson E. Byrn, "United Airlines Station Manpower Planning System," *Interfaces*, Vol. 16, 1 January - February 1986, pp. 39-50.

[13] Swords, S., *A Monthly Sortie Scheduling Model for Improved EA-6B Prowler Combat Readiness*, Master's Thesis, Naval Postgraduate School, Monterey, March 1998.

[14] Rumchev, V.G., "Control of Manpower Systems," *Systems Science*, Vol. 5, No. 1, 1979, pp.103-117.

[15] Lanzenauer, Christoph, "A Production Scheduling Model by Bivalent Linear Programming," *Management Science*, Vol. 17, No. 1, 1970, pp.105-111.

[16] Seccatore, L., *Course Scheduling to find the Minimum Cost Set of Facilities Required*, Master's Thesis, Naval Postgraduate School, Monterey, September 1973.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
   8725 John J. Kingman Rd., STE 0944
   Fort Belvoir, Virginia 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Rd.
   Monterey, California 93943-5101

3. Assistant Deputy Chief of Staff for Training 1
   Headquarters, U.S. Army Training and Doctrine Command
   Fort Monroe, VA 23651

4. Colonel David C. Arney 1
   United States Military Academy
   Department of Mathematical Sciences
   West Point, NY 10996

5. Colonel Michael McGinnis 1
   United States Military Academy
   Department of Systems Engineering
   West Point, NY 10996

6. Office of the Deputy Chief of Staff for Personnel 1
   ATTN: Colonel Kaylor, USA
   DAPE-PRS Rm 2C744
   US Army Pentagon
   Washington DC 20310-0300

7. Associate Professor LTC David Olwell 2
   Code OR/Ol
   Department of Operations Research
   Naval Postgraduate School
   Monterey, California 93943-5000

8. Colonel Susan Cheney 1
   13 York Road
   Upavon, Pewsey
   Wiltshire, SN9 6BQ, Great Britian

9. Professor Gerald G. Brown 1
   Code OR/Bw
   Department of Operations Research
   Naval Postgraduate School
   Monterey, California 93943-5000

10. Headquarters, U.S. Army Training and Doctrine Command 1
    Training Development and Analysis Agency
    ATTN: Chief, Operations Research and Analysis Division
    Fort Monroe, VA 23651-5000

11. CPT Marie L. Hall USA 1
    United States Military Academy
    Department of Mathematical Sciences
    West Point, NY 10996